HIDALGO2
CENTRE OF EXCELLENCE

Urban Air Project

Castiel 2 – Code of the month presentation

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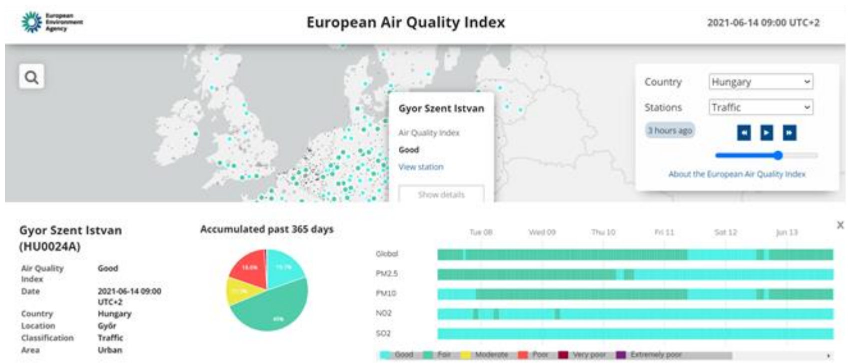
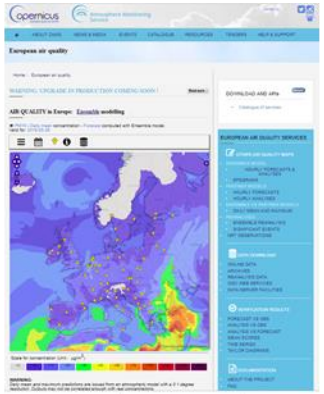
Contents

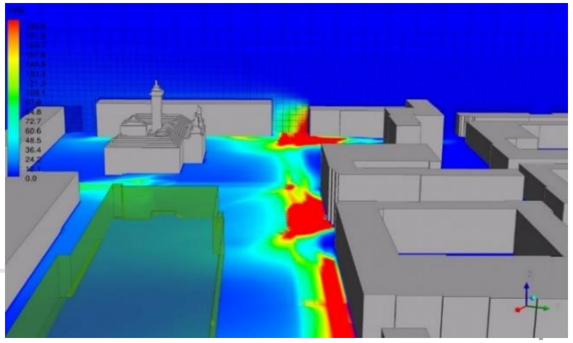
1. The global challenge: tackling urban air pollution

- EU Ambient Air Quality Directive https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/734679/EPRS_BRI(2022)734679_EN.pdf
  - Each EU country must report annual measures of air quality and punish violations.
  - Suitable proven digital solutions are eligible for reporting and policymaking
- **Current supporting services** of the EU: Monitoring, forecasts, and reanalysis for air quality of several cities on a coarse mesh (**10 km x 10 km**), see e.g.: https://airindex.eea.europa.eu/Map/AQI/Viewer/.





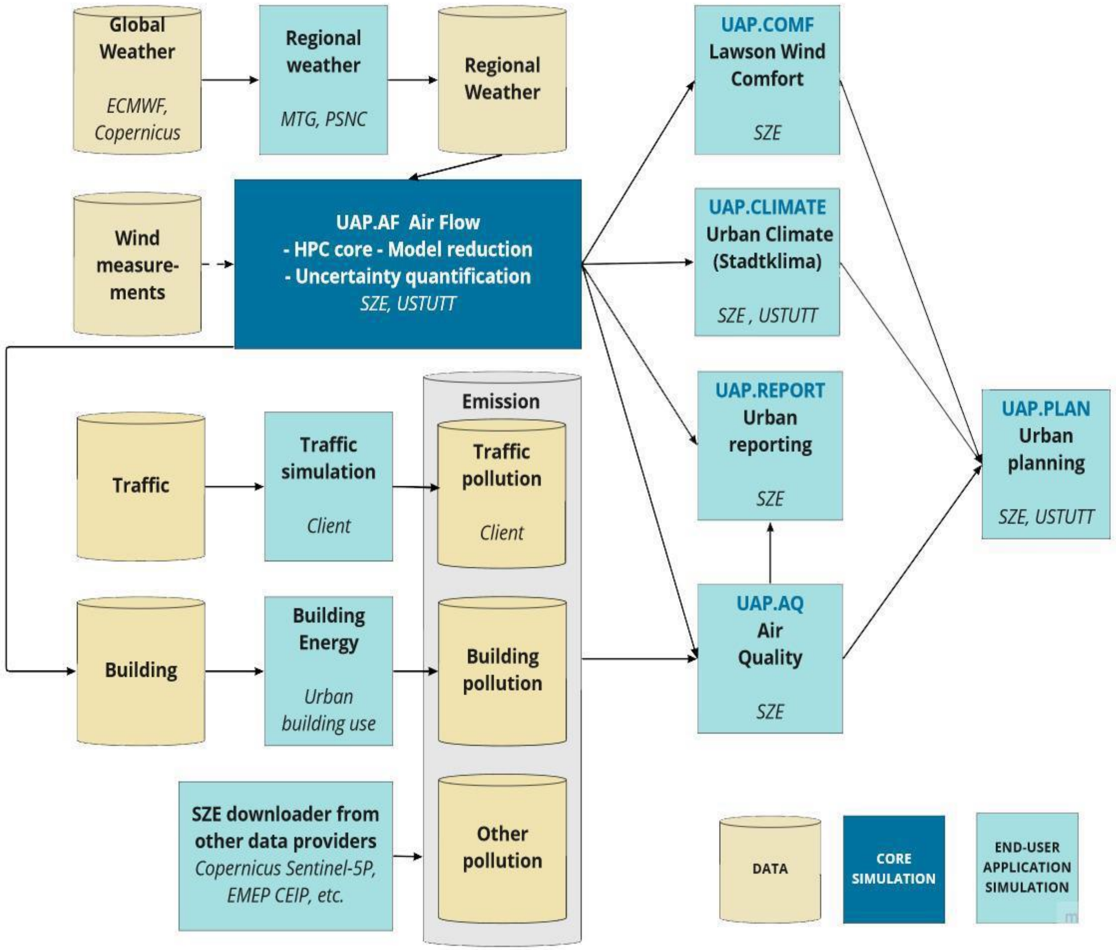
- **Pain point**: In many cities, local hot-spots (regions with excessive pollution) have been forming. Detection and evaluation of health effects of hot-spots are impossible with using simulations on coarse meshes. → **HPC, exascale**



1. Global challenges and business points

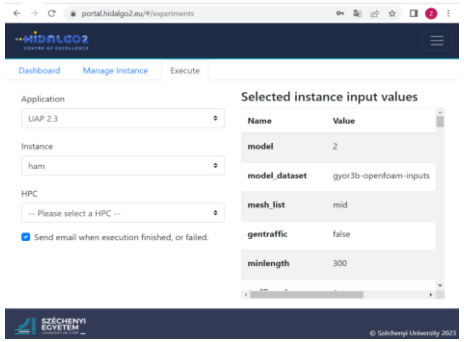
1. UAP.AQ: **Air quality simulation for cities at 1-2 meter resolution**
    1. EU regulations have been proposed to be changed according to WHO's very strict thresholds (link)
    2. KPIs from EU regulations: threshold values, and monthly/annual mean concentrations and exceedance values for concentrations of gases (NO2, O3) and small particles (PPMs)
    3. Extreme computing of the dispersion of the accidental/intentional gas release
    4. Potential customers: National authorities, cities, defense
2. UAP.AC: **Computational design assessment for urban pedestrian air/wind comfort and safety**
    1. Urban wind can cause discomfort for pedestrians and even critical safety situations, in particular near high buildings, see e.g. Chicago (the „Windy City"), Shinjuku District, Tokyo.
    2. Potential customers: cities, designer companies
3. UAP.AP: **Urban planning**
    1. Develop computational tools serving urban designers and policymakers to mitigate or cease the negative effects of urban challenges (Easy-to-use, tailored user interface, HPC in the background)
    2. Potential customers: cities, architectural designer companies
4. CFD-GPU: **Native exascale CFD for compressible fluids on multi-GPUs**
    1. Develop solvers (e.g. RedSim) for MPI+multiGPU scaling on exascale problems
    2. Potential customers: industry (aerospace, automotive, …), interdisciplinary research

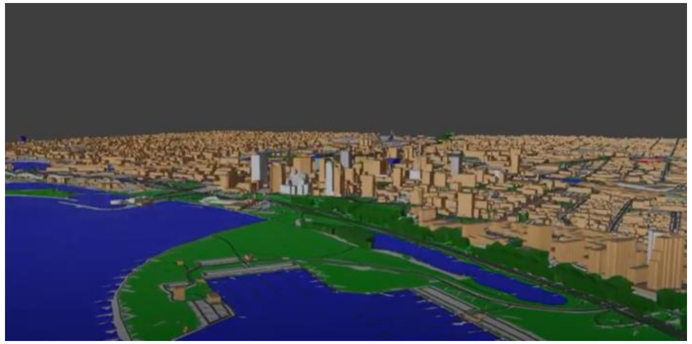
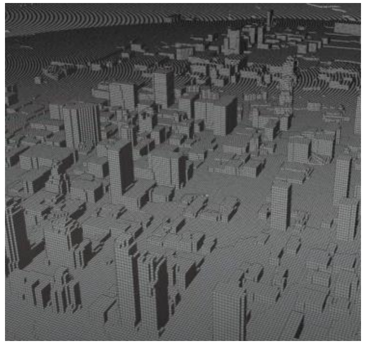
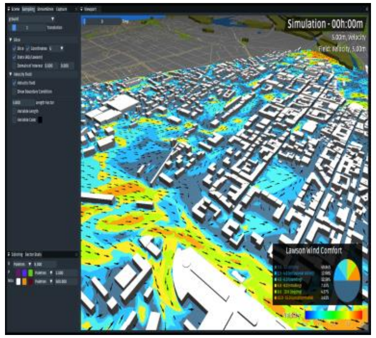
2.1 The UAP application and codes with demonstrations - Workflow



2.1 Overview of the UAP application from the portal

- **MathSO-portal: Automated deployment of containerized solutions to HPC platforms** with
  - Configuration (on the web application)
  - Preprocessing (geometry from OpenStreetMap, meshing),
  - Simulation (OpenFOAM, RedSim), and
  - Visualization (with CFDR).



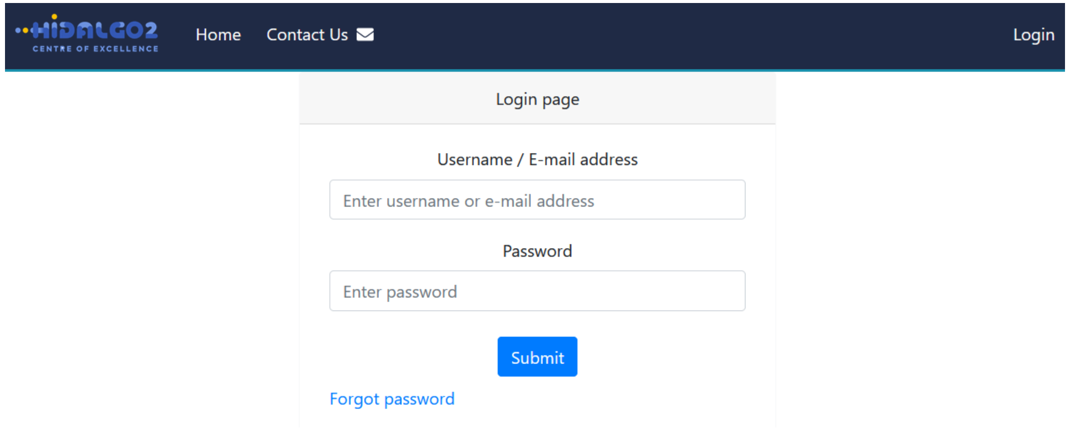





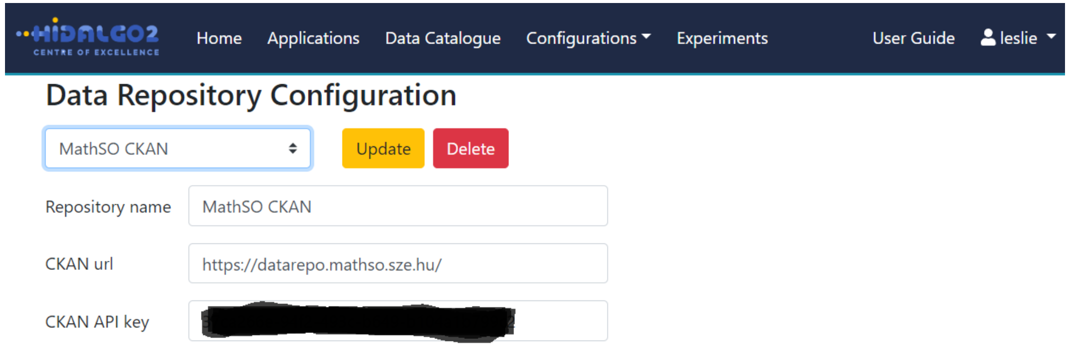
2.1 Overview of the UAP application from the portal

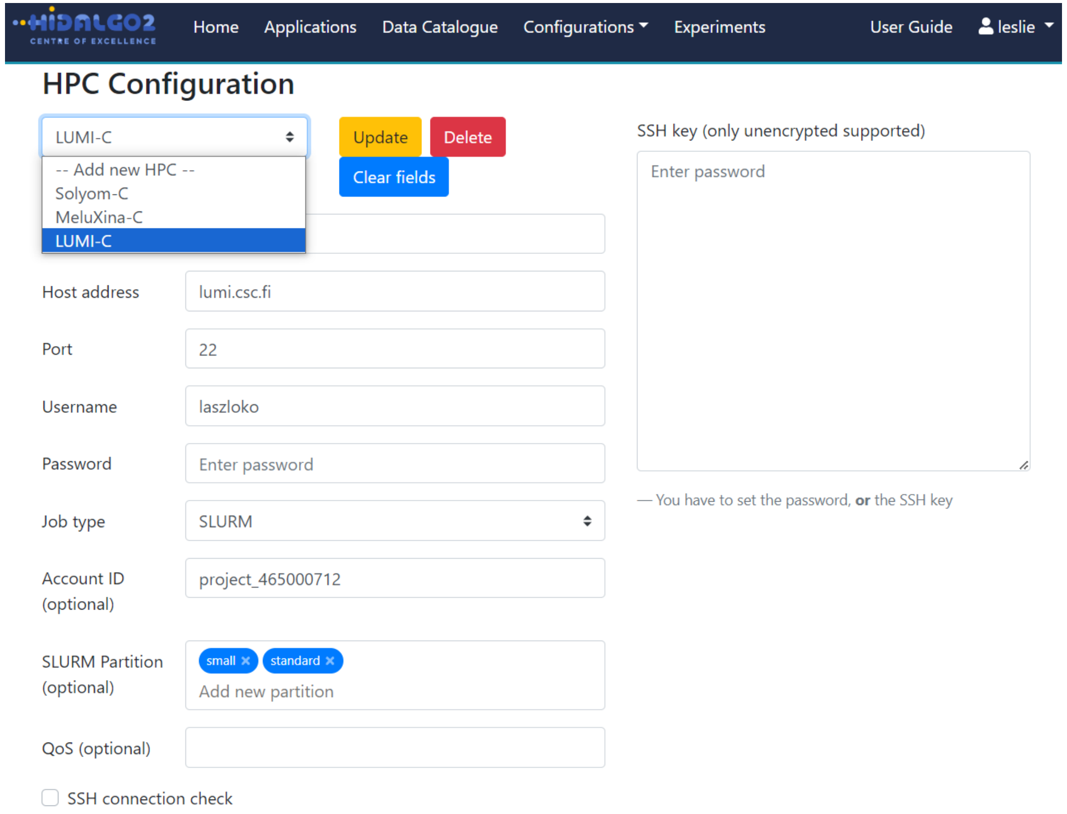
Overview of the chapter on the HiDALGO2 Portal

- Features and Configuration
- UAP-FOAM deployment on EuroHPC machines
- Pilot blueprint, Workflow orchestration
- Integration and deployment workflow

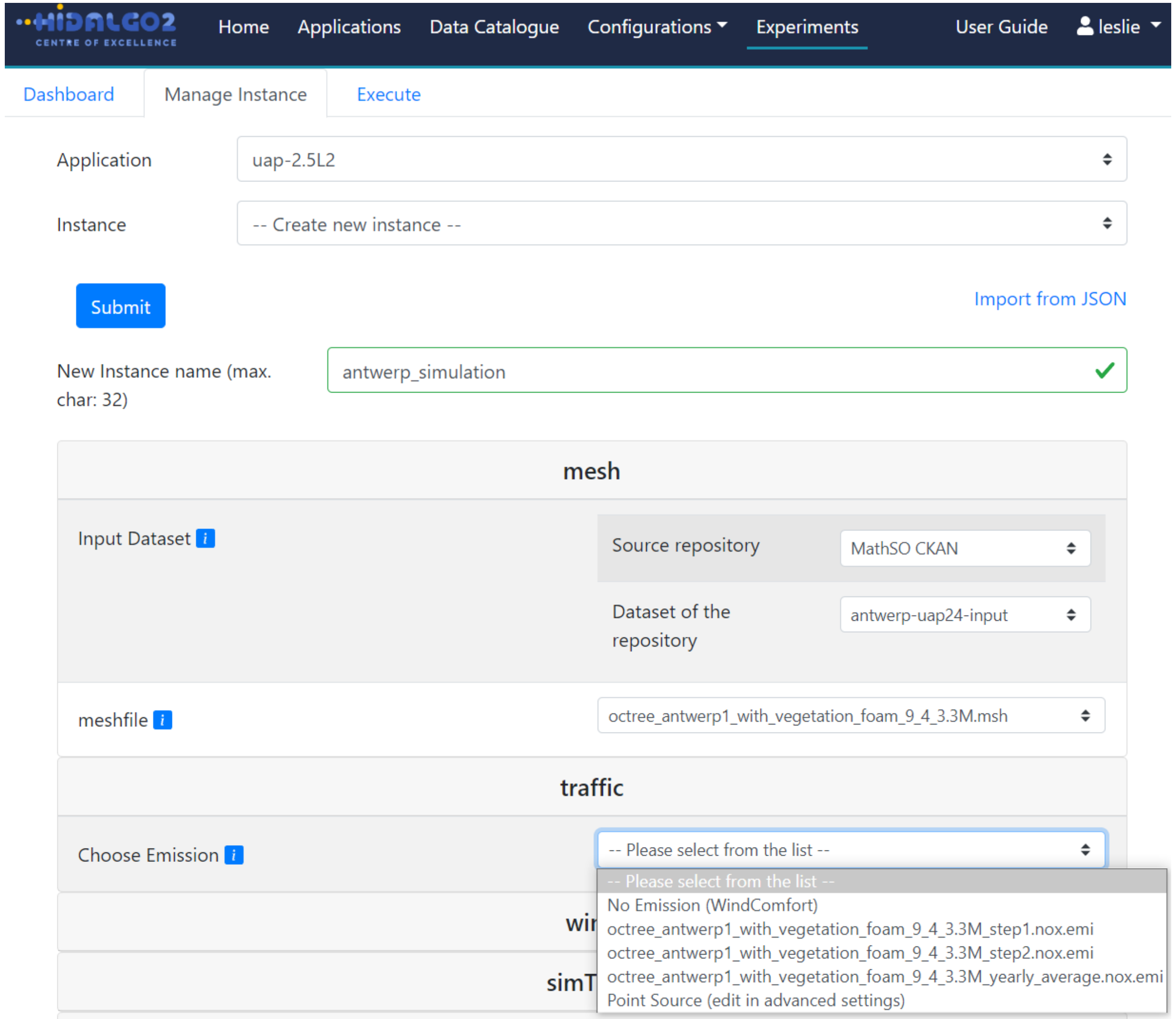
HiDALGO2 Portal Configuration and Features

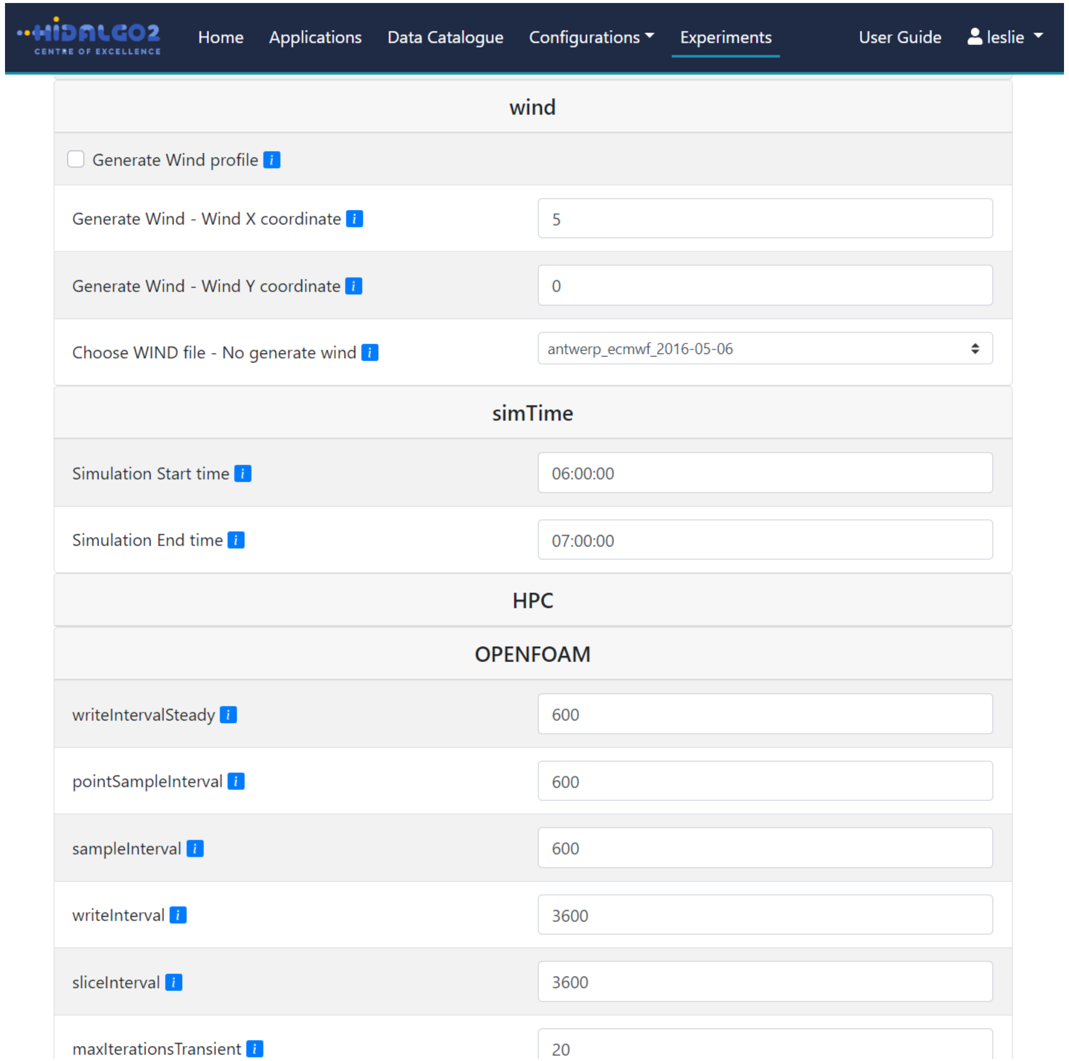




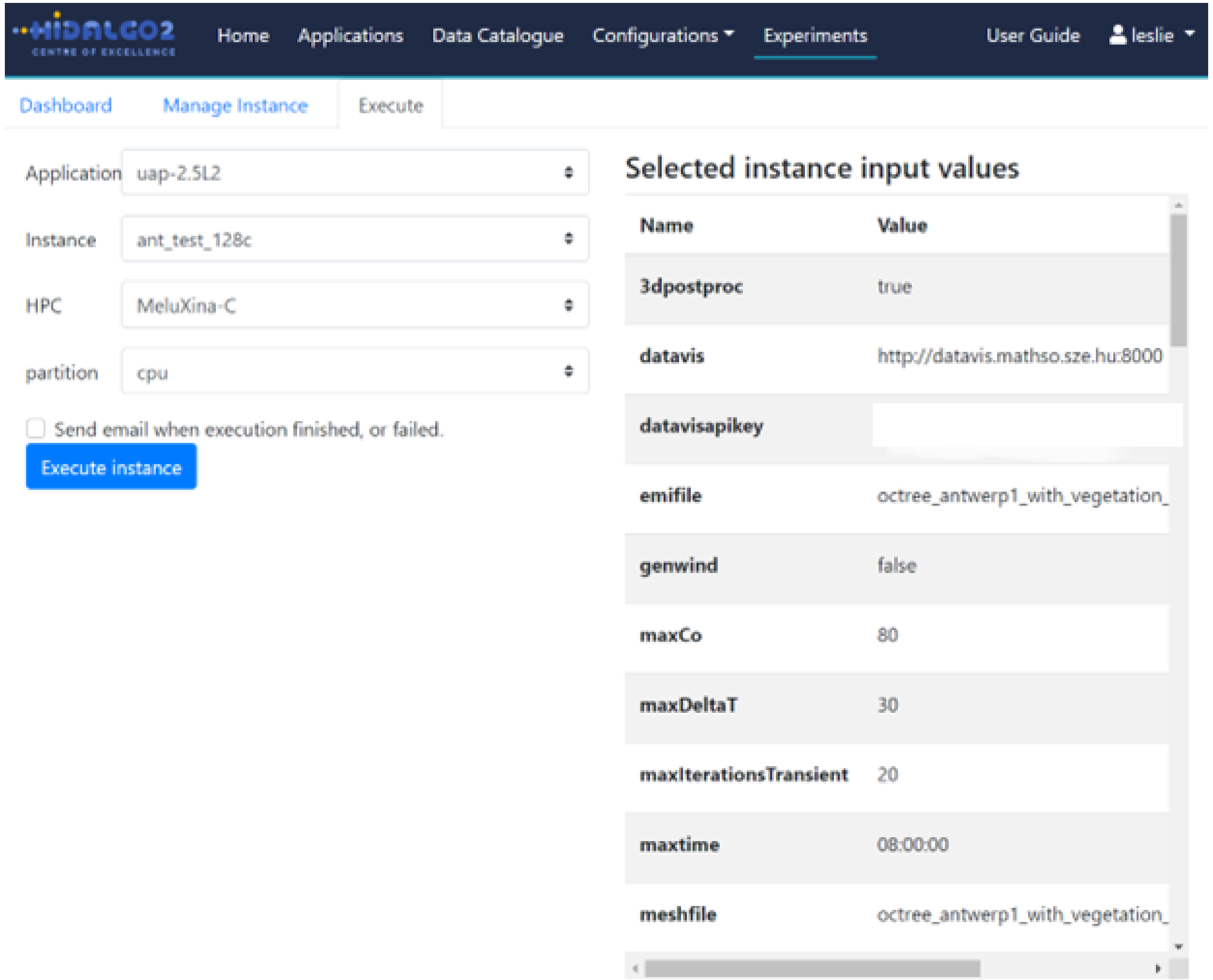


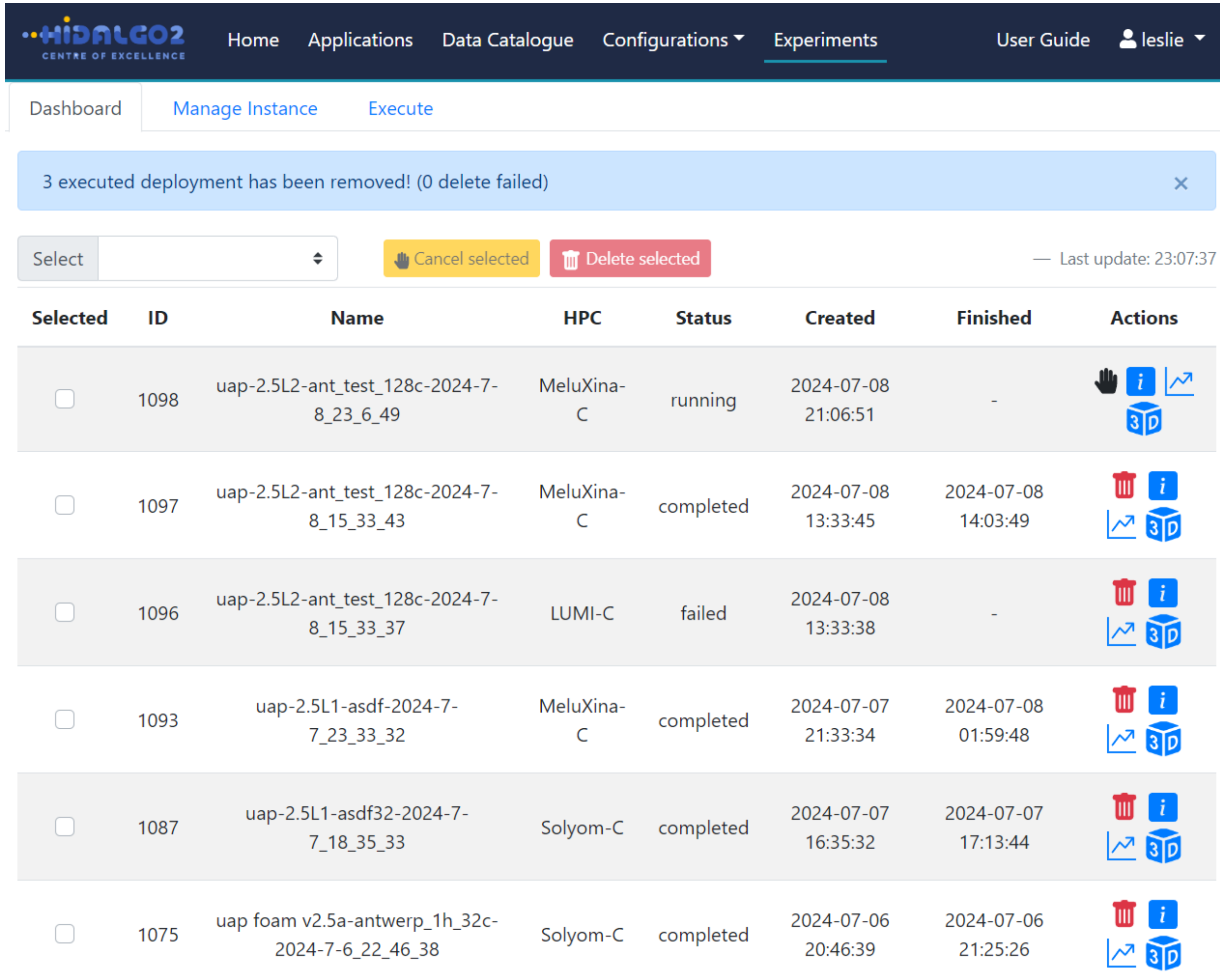
Portal - UAP-FOAM - Configure simulation



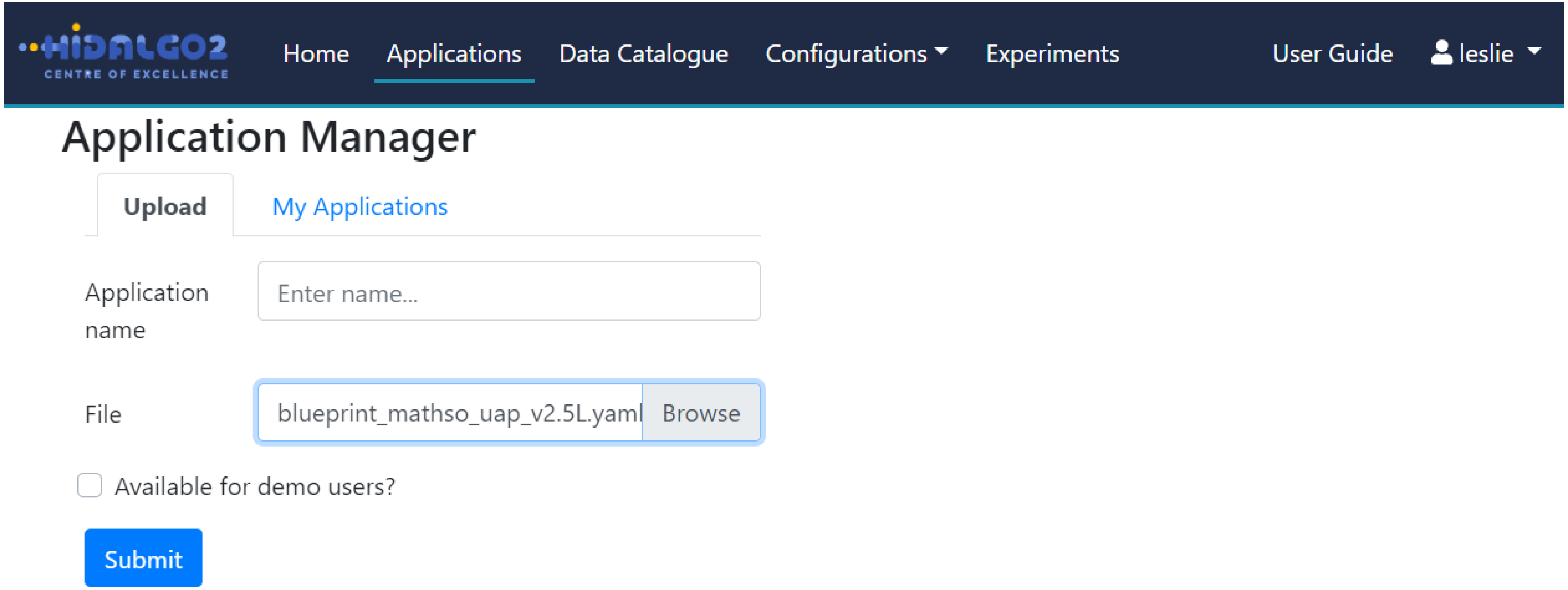


Portal UAP-FOAM - Submit and Monitor

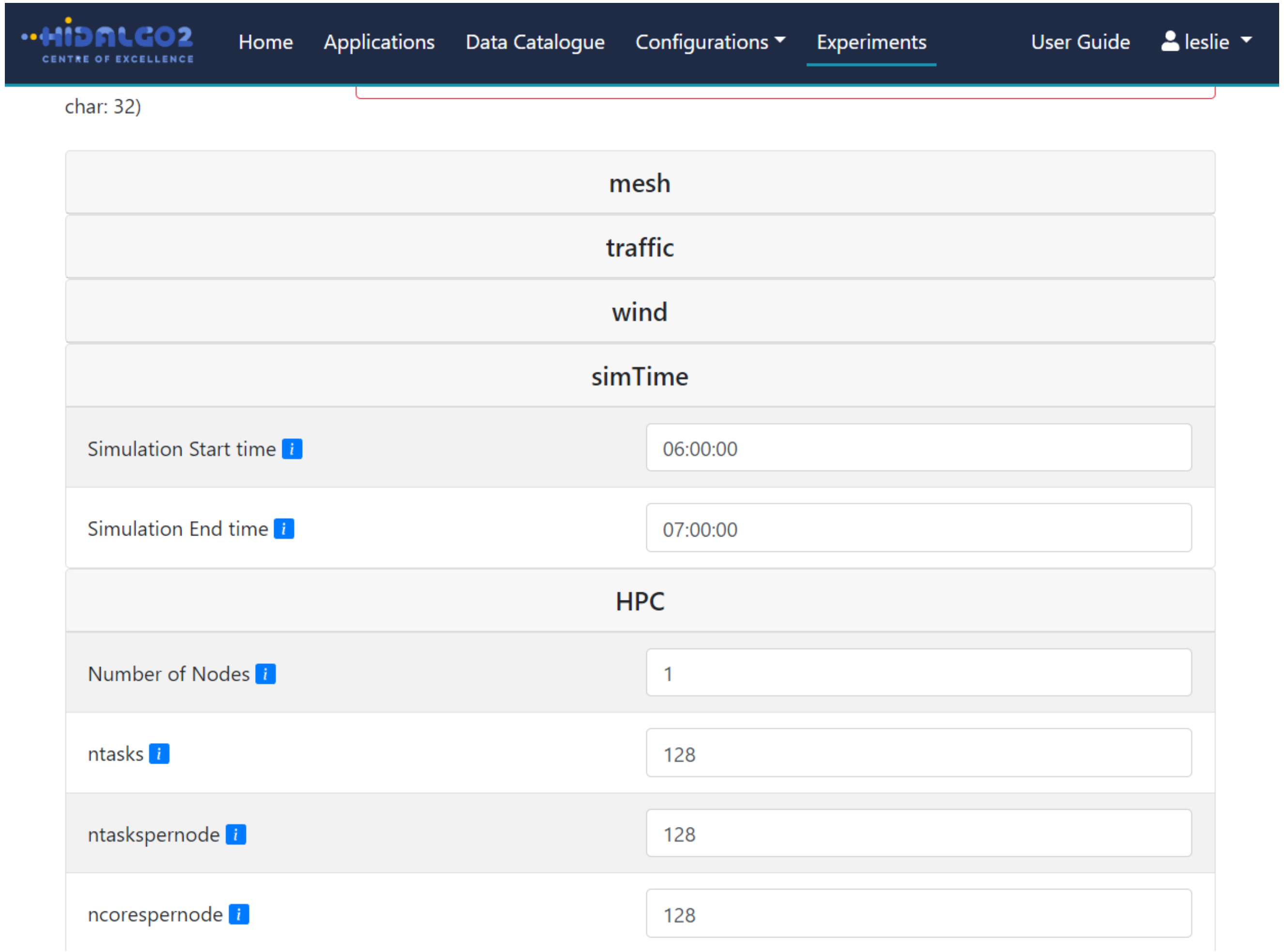




Portal Application Manager



UAP-FOAM Blueprint input fields

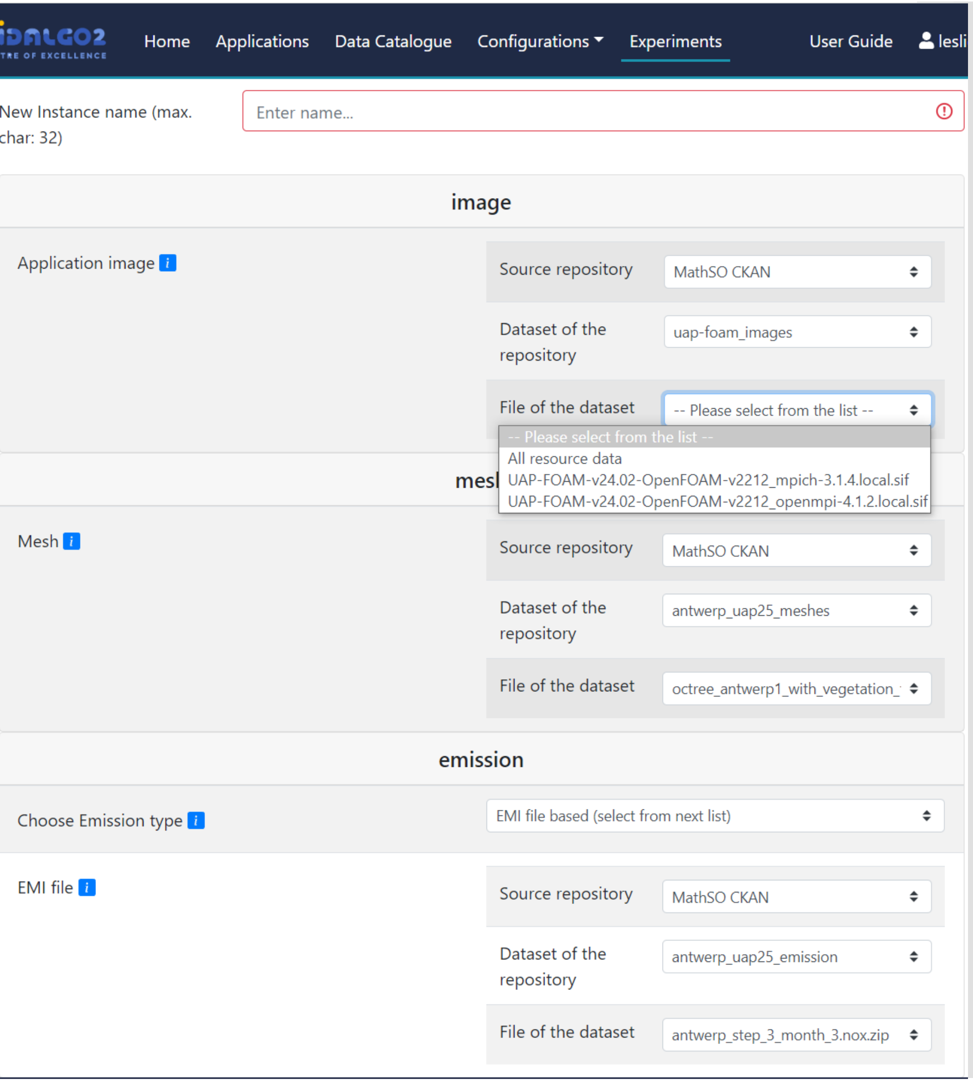



```yaml
simstarttime:
  name: Simulation Start time
  description: "Simulation Start time"
  default: "00:00:00"
  type: text
  group: simTime
  order: 9
  optional: false

simendtime:
  name: Simulation End time
  description: "Simulation End time"
  default: "23:59:00"
  type: text
  group: simTime
  order: 10
  optional: false


jobmanager_list:
  name: Jobmanager
  description: "Choose the used JobManager"
  type: hidden
  default: "SLURM"
  group: HPC
  order: 11
  optional: false

nnodes:
  name: Number of Nodes
  description: "Number of Nodes"
  default: "2"
  type: text
  group: HPC
  order: 40
  optional: false
```

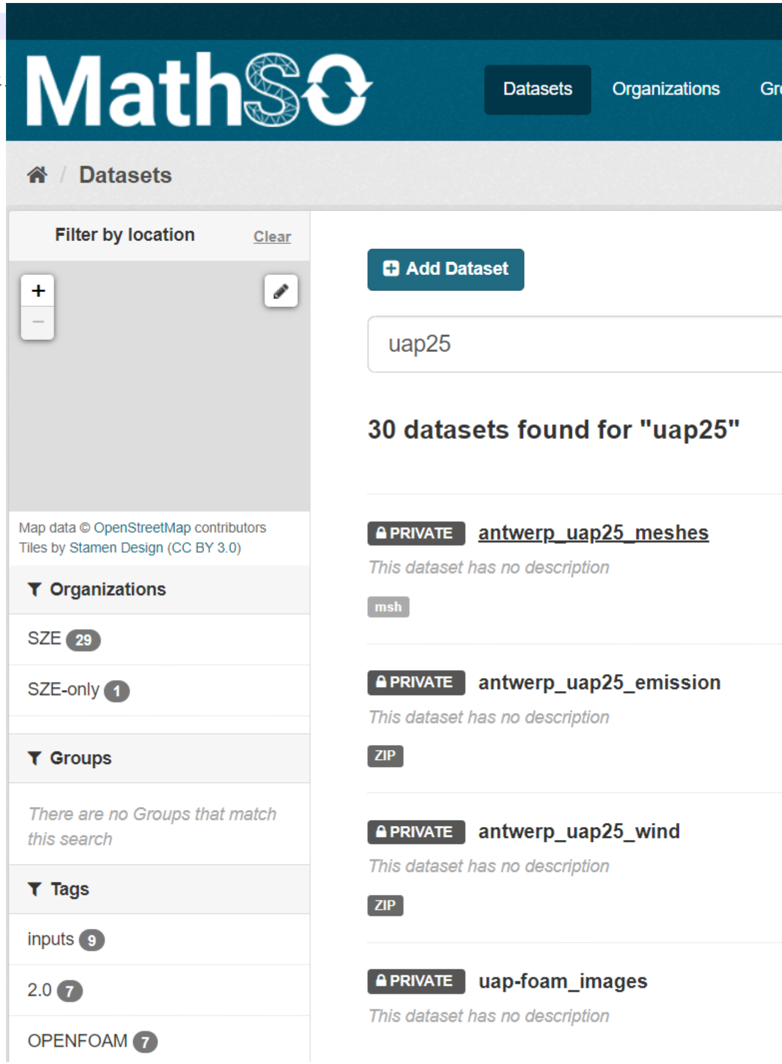
UAP-FOAM Workflow in TOSCA

```yaml
    copying:
        type: hpc.nodes.Job
        properties:
            job_options:
                type: 'HEAD'
                command: { concat: [ 'wget ', { get_input: pilot_url }
            deployment:
                #bootstrap: 'scripts/bootstrap_traffic.sh'
                #revert: 'scripts/revert_traffic.sh'
            skip_cleanup: true

    sim_conf:
        type: hpc.nodes.Job
        properties:
            job_options:
                type: 'HEAD'
                command: { concat: [ 'sleep 15 && ./mathso-gencfg.sh '
        relationships:
            - type: job_depends_on
              target: copying
    preproc:
        type: hpc.nodes.Job
        properties:
            job_options:
                type: 'SRUN'
                command: './run.sh'
                nodes: '1'
                tasks: '1'
                cpus_per_task: '12'
                max_time: 01:00:00
            deployment:
                #bootstrap: 'scripts/bootstrap_traffic.sh'
                #revert: 'scripts/revert_traffic.sh'
            skip_cleanup: true
        relationships:
            - type: job_depends_on
              target: sim_conf

    simu:
        type: hpc.nodes.Job
        properties:
            job_options:
                type: 'SBATCH'
                command: './cfd/simulate.job'
                max_time: '48:00:00'
                std_out: 'slurm_out'
                err_out: 'slurm_err'
            deployment:
                #bootstrap: 'scripts/bootstrap_traffic.sh'
                #revert: 'scripts/revert_traffic.sh'
            skip_cleanup: true
        relationships:
            - type: job_depends_on
              target: preproc

    upload:
        type: hpc.nodes.Job
        properties:
            job_options:
                type: 'HEAD'
                command: './upload.sh'
                std_out: 'upload_out'
                err_out: 'upload_err'
            deployment:
            skip_cleanup: true
        relationships:
            - type: job_depends_on
              target: simu

expected_results:
    - type: 2D
    - type: 3D
```

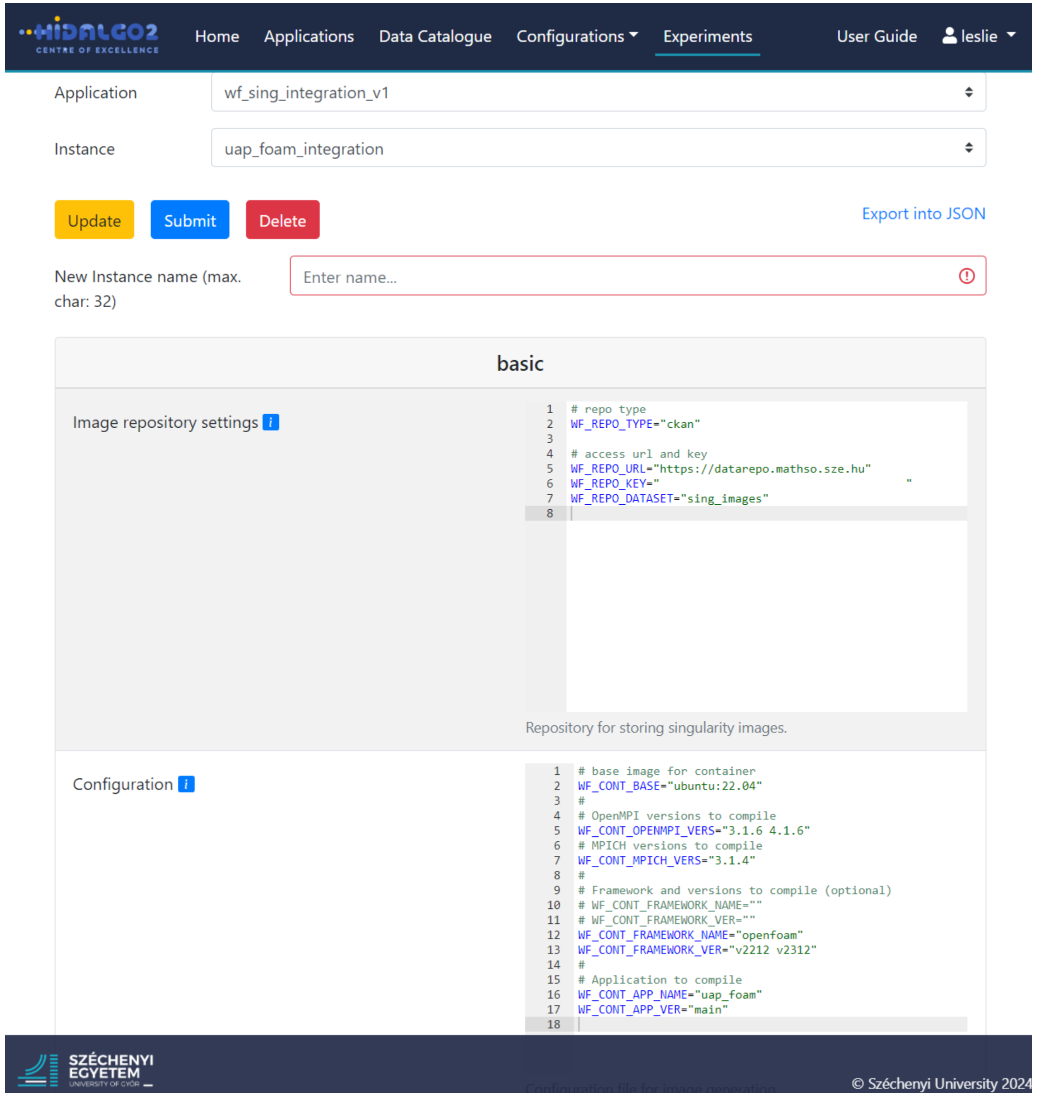
Portal new features

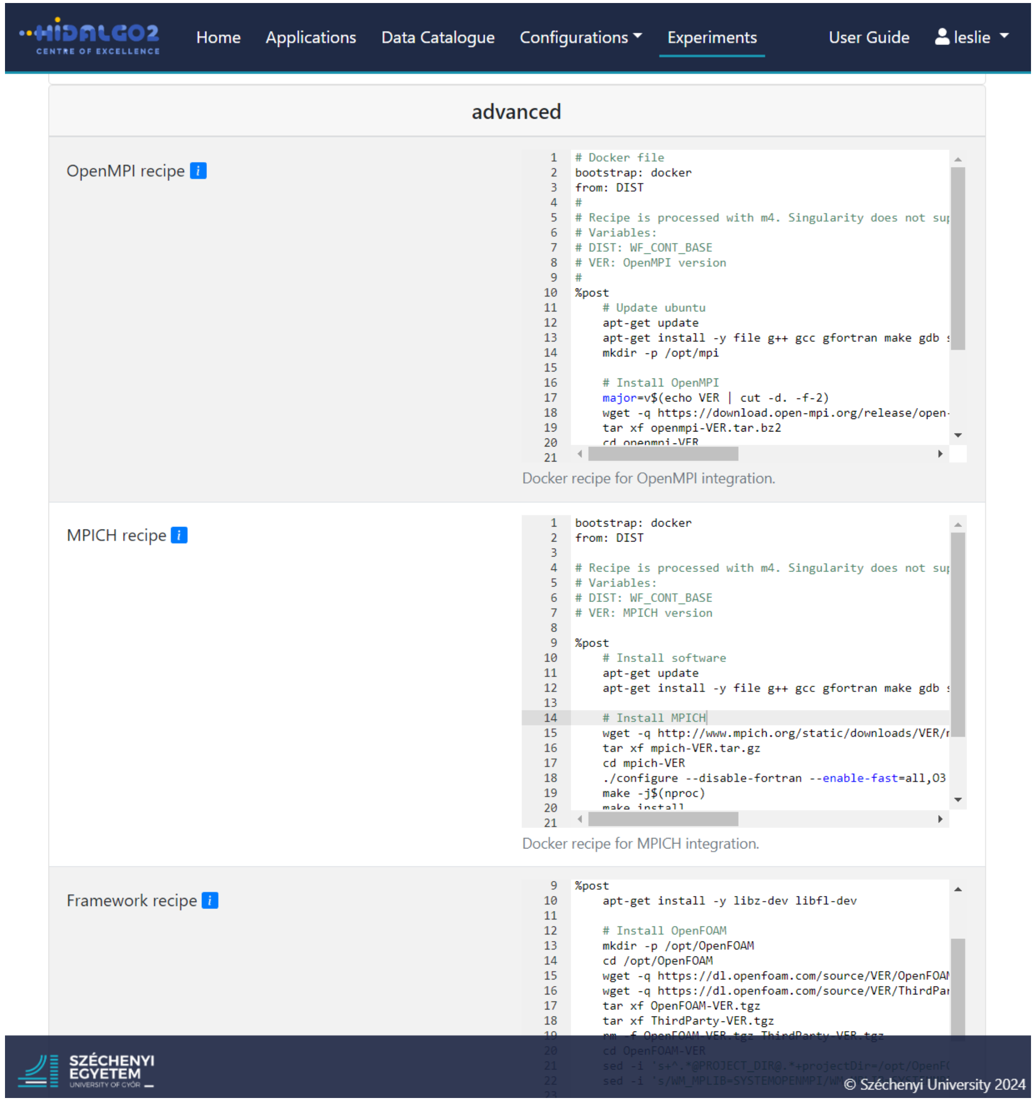



```yaml
app_image:
  name: Application image
  description: Singularity image for UAP-FOAM applicat
  default: ""
  type: ckan_file
  ckan_tag: uap25 image
  group: image
  order: 2
  optional: false
  dataset_optional: false

model_mesh:
  name: Mesh
  description: Mesh dataset and mesh.
  default: ""
  type: ckan_file
  ckan_tag: uap25 mesh
  group: mesh
  order: 3
  optional: false
  dataset_optional: false

emitype:
  name: Choose Emission type
  description: "Choose Emission Type Source"
  type: list
  choices:
    - first:
      text: No Emission (WindComfort)
      value: noemission
    - second:
      text: EMI file based (select from next list)
      value: emiemission
    - fifth:
      text: Point Source (edit in advanced settings)
      value: pointsource
  group: emission
  order: 11
  optional: true
```

Portal - UAP-FOAM to Container integration





2.2 CFD codes in UAP

1. **OpenFOAM**
    1. 3D incompressible Navier-Stokes,, FVM on unstructured meshes, RANS and URANS, (pimpleFOAM, simpleFOAM), passive scalar (for pollutant dispersion)
    2. Optimized code for CPU (OpenMPI)
        1. **Parallel efficiency: >80% (#cells=10M)**
    3. 1 paper published, joint with the other (non-HPC) FAIRMODE-teams

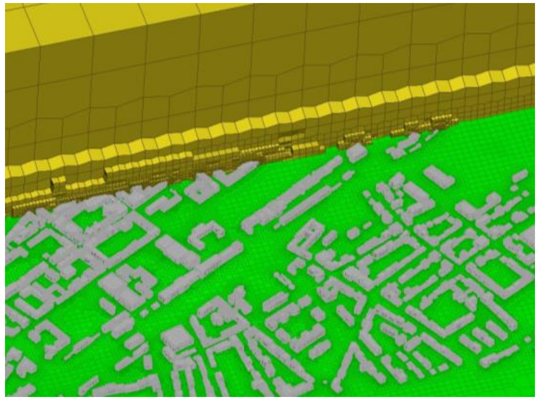
2. **RedSim**
    1. C/C++/CUDA code for 2D/3D Euler and Navier-Stokes, compressible, 1st & 2nd order FVM, unstructured polyhedral meshes, reduced order mode (POD, POD-DEIM)
    2. Optimized code for CPU (OpenMPI, cray-mpich on LUMI), Multi-GPU (CUDA, NVLINK), randomized SVD
        1. **Parallel efficiency > 85% with 8 GPUs (KAROLINA) and #cells = 30M**

3. **Testing: Xyst CFD code**
    1. 3D Navier-Stokes, compressible, FEM on unstructured tetrahedral mesh, adaptive load distribution, asynchronous parallel programming with the Charm++ runtime system, Low-Mach solver under development
    2. Optimized code for CPU (OpenMPI), started as a fork of the Quinoa-code, https://quinoacomputing.github.io

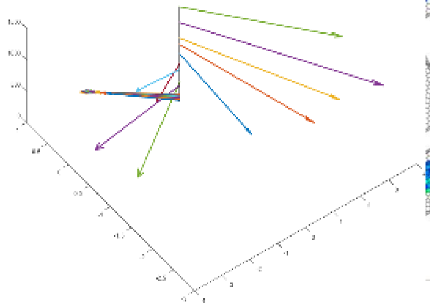
2.2 UAP-FOAM

- Input
  - 3D Mesh City Model
  - Weather-based boundary, ECMWF coupled
  - Traffic or point-based pollution source
- Equations and solution
  - Incompressible URANS solved with k-e turbulence model
  - NOx Pollution s calculated with scalar transport with volumetric source S_s.
  - Transient simulation with PIMPLE method, initialized with SIMPLE method

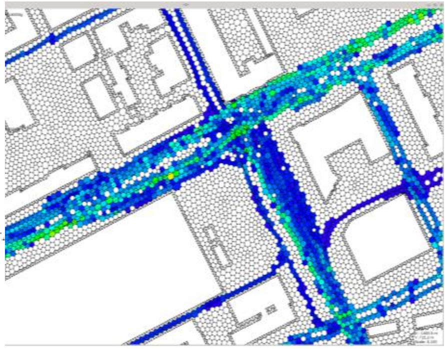
Model



Boundary



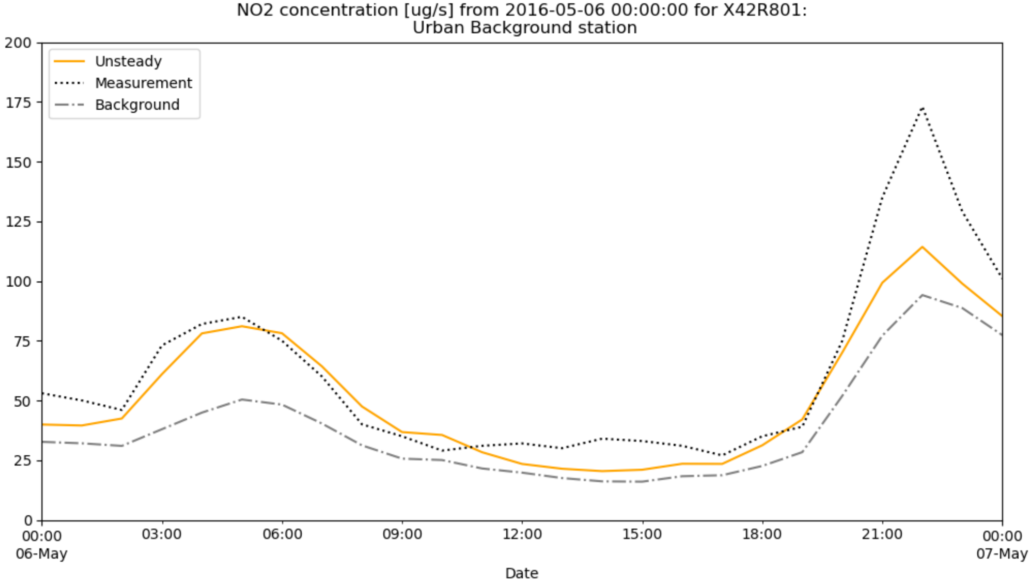
Traffic

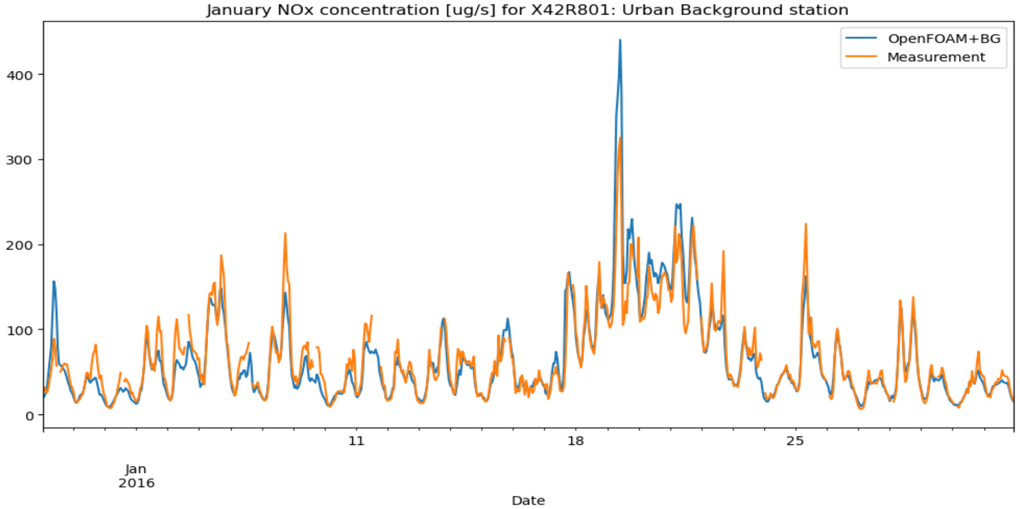


3D Result

UAP-FOAM Validation

- Antwerp, 2016, full year simulation, measured wind data, yearly average based traffic modelling
- 2 EU measurement stations, several passive samplers
- Comparison with several modelling groups in FAIRMODE: Martin et. al., STOTEN, Volume 925, May 2024, 171761





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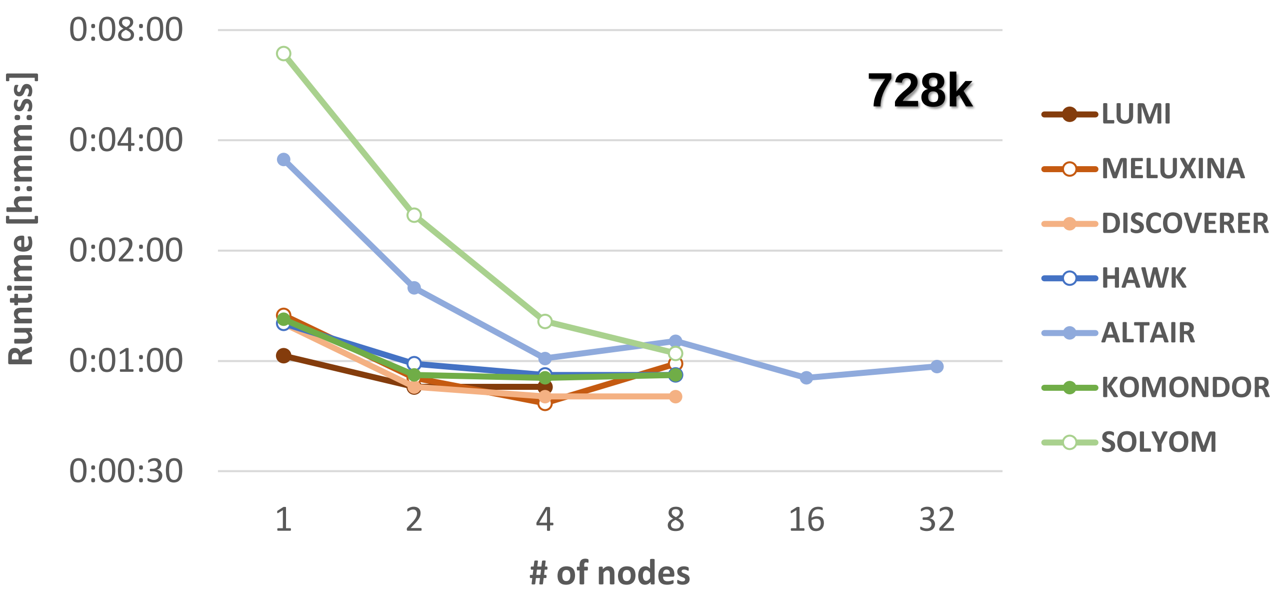
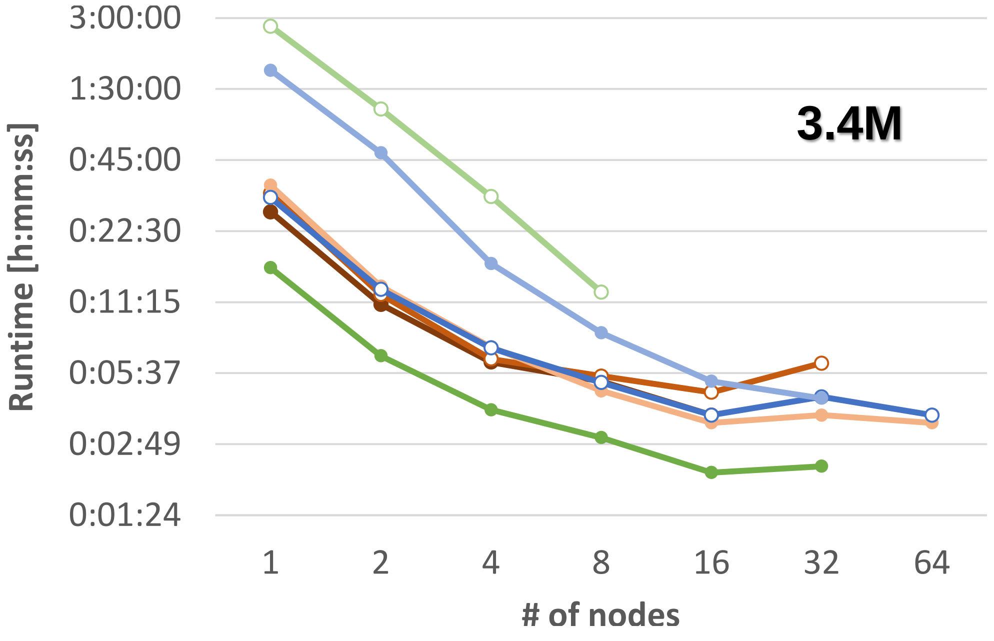
2.2 UAP-FOAM Benchmark - Hardware Overview

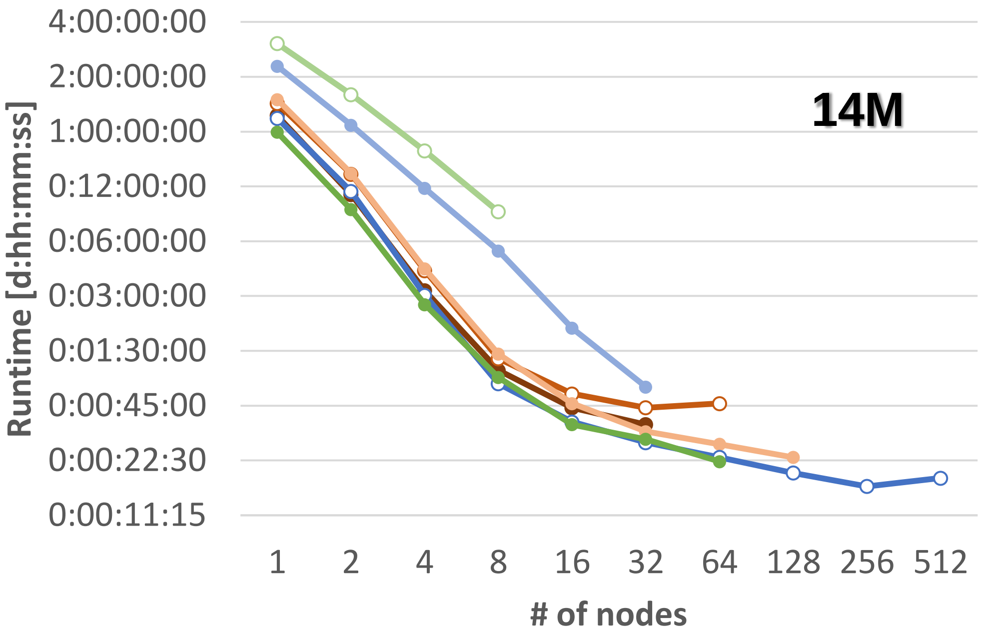
		LUMI	MELUXINA	DISCOVERER	HAWK	ALTAIR	KOMONDOR	SOLYOM
Location		Finland	Luxembourg	Bulgaria	Germany	Poland	Hungary	Hungary
# of CPU nodes available		1022	573	1110	5632	1321	184	12
# of sockets per node		2	2	2	2	2	2	2
# of cores per socket		64	64	64	64	24	64	16
# of cores total		130816	73344	142080	720896	63408	23552	384
CPU	*vendor*	AMD	AMD	AMD	AMD	INTEL	AMD	INTEL
	type	EPYC 7763	EPYC 7H12	EPYC 7H12	EPYC 7742	XEON 8268	EPYC 7763	XEON 6226R
RAM per node		256 GB	512 GB	256 GB	256 GB	192 GB	256 GB	192 GB
Interconnect	*type*	Slingshot	Infiniband	Infiniband	Infiniband	Infiniband	Slingshot	Infiniband
	card	SS11	MT4123	MT4123	HDR	MT4119	SS11	MT4123
	BW	200 Gbit/s	200 Gbit/s	200 Gbit/s	200 Gbit/s	100 Gbit/s	200 Gbit/s	100 Gbit/s
Compiler		cray clang	gnu gcc	gnu gcc	gnu gcc	gnu gcc	gnu gcc	gnu gcc
	version	14.0.2	11.3.0	11.3.0	9.2	10.2	12.2.0	9.4.0
MPI		cray-mpich	openmpi	openmpi	hpe mpt	openmpi	cray-mpich	openmpi
	version	8.1.18	4.1.4	4.1.4	2.23	4.1.0	8.1.24	4.1.2
OpenFOAM	*version*	v2112	v2206	v2206	v2012	v2012	v2112	v2112

LUMI MELUXINA DISCOVERER HAWK ALTAIR KOMONDOR SOLYOM

2.2 Benchmarking: UAP-FOAM Runtime

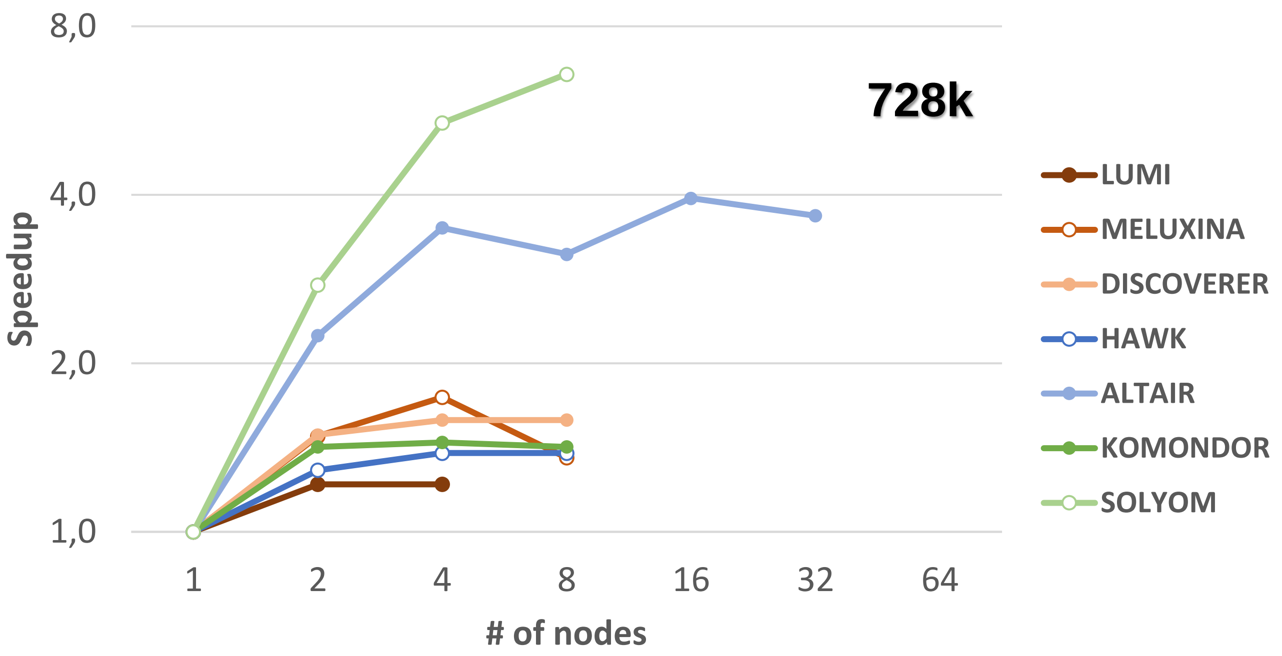


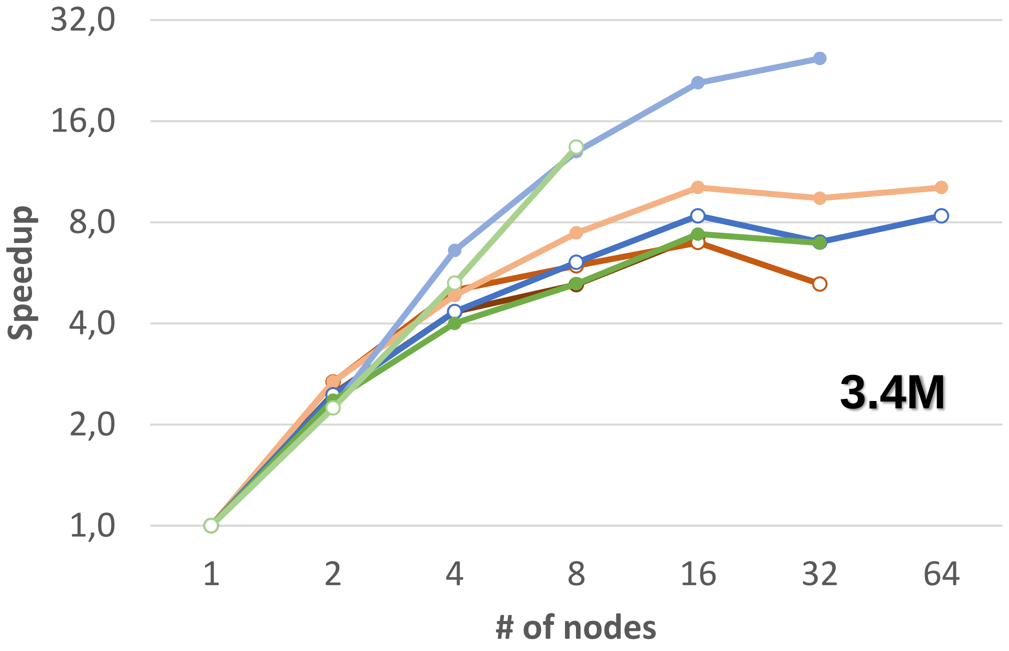


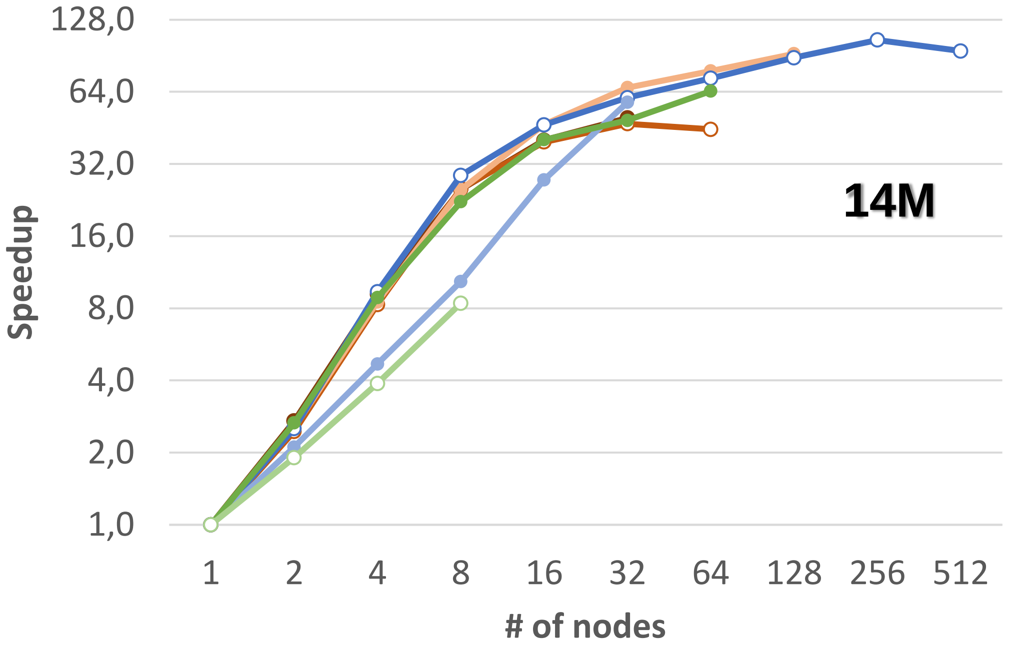


- Győr geometry with mesh sizes 728k, 3.4M, 14M
- Testruns on 7 architectures
- Runtime estimation [hh:mm:ss] for 1h simulated time

2.2 Benchmarking: UAP-FOAM Speedup

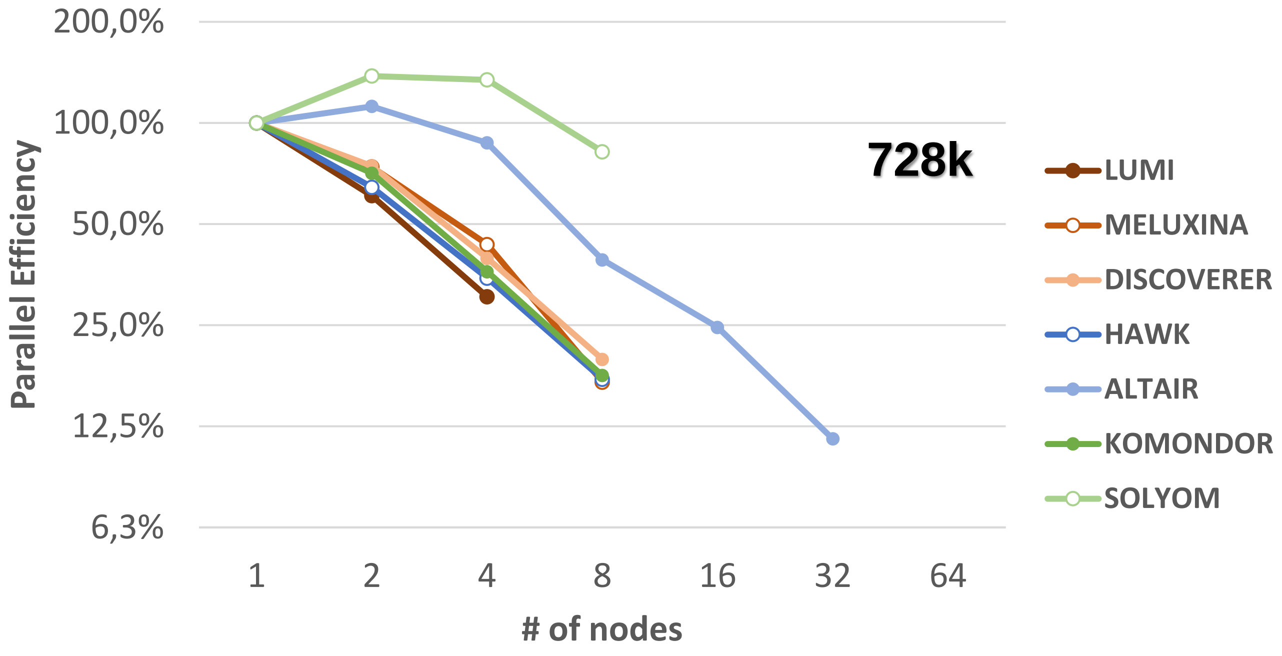


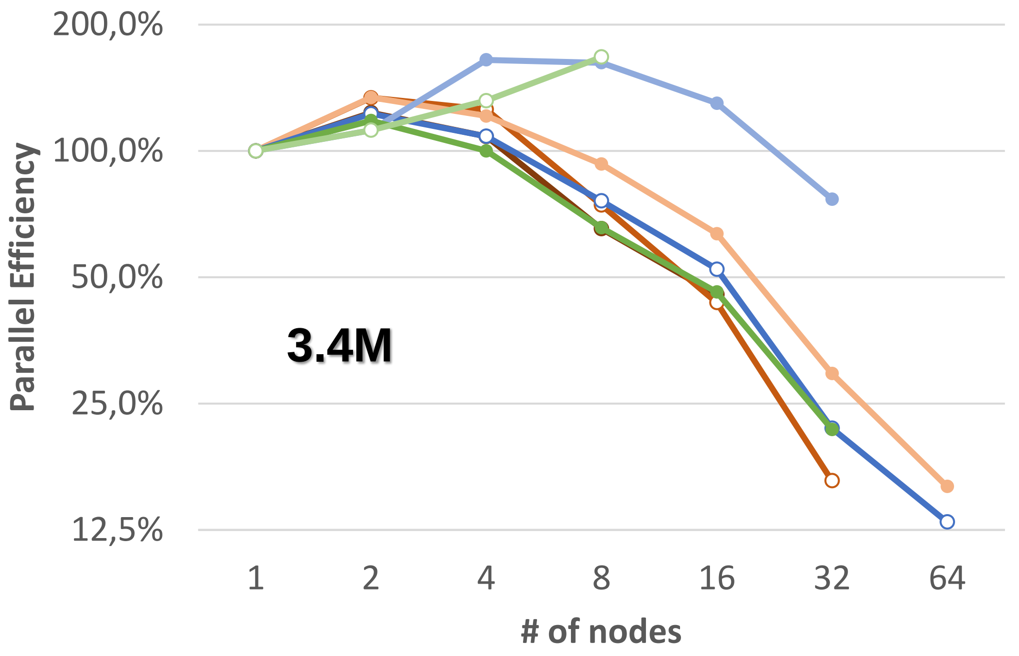


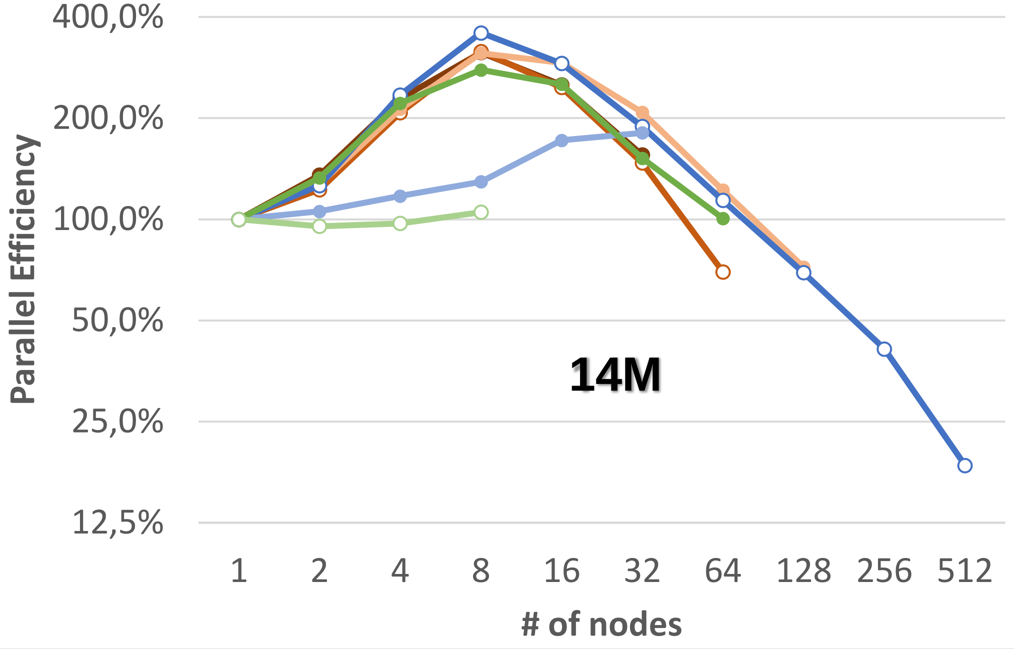


- Győr geometry with mesh sizes 728k, 3.4M, 14M
- Testruns on 7 architectures
- Speedups with regard to 1 node

2.2 Benchmarking: Parallel Efficiency







- Győr geometry with mesh sizes 728k, 3.4M, 14M
- Testruns on 7 architectures
- Parallel efficiency with regard to 1 node

2.3 The RedSIM and CFDR software

https://redsim.mathso.sze.hu/

RedSim:

- native multi-GPU CFD-solver to simulate compressible fluids on unstructured, polyhedral meshes.

CFDR:

- visualization software for CFD running on HPC and to visualize data on your web browser live.

API:

- expressive, compact API written in Lua, helps the users to write their applications with RedSim and CFDR.

2.3 The RedSIM software: The FOM algorithm

Algorithms and data structures

1. Solves the compressible Euler and Navier-Stokes equations with the ideal equation of states (EOS)
2. Uses finite volume method for the spatial (semi)discretization
    1. Control volumes = unstructured polyhedra
    2. Upwinding with the Vijayasundaram flux-vector splitting
    3. 2nd order scheme with averaging to vertices and linear reconstruction on faces
3. (Yet) Explicit time-stepping with the Euler and optimal TVD schemes
4. One single algorithm for 2D/3D computations
5. Input/Output data formats: industrial standards, e.g. Ensight Gold, Nastran.

2.3 The RedSim software: the reduced order algorithm

Algorithms

- Basic method: the POD – proper orthogonal decomposition method
    - Snapshot collection from the representative states and the SVD to define the projections
- Several variants of DEIM (discrete empirical interpolation methods) are implemented for numerical performance purposes
- For the snapshot collection the RedSim FOM multi-GPU version was applied
- For the SVD computations
    - From the Eigen library, and
    - the RedSVD randomized numerical solver, see https://github.com/cequencer/redsvd

2.3 The RedSIM software: Code features

Coding style

- Developed from scratch by the authors (algorithms: ZH, programming: MC)
- Written in C99-style, compiled as C++, avoids C++ features (RAII, reflections, exceptions, ...)
- Custom memory allocators, such as Linear Arena, Heaps, or Pools when appropriate; no use of new
- ”Data Oriented Approach” (cf. Mike Acton), SOA paradigm
- One single algorithm and one source file, runs easily on each platform
- Parallel:
    - CPU (OpenMPI + OpenMP)
    - Multi-GPU (with CUDA)
- One single algorithm and code for handling 2D/3D
- Integrated in-house real-time 3D visualizer
- Reconfigurable during running, due to suitable lua-scripts
- Highly optimized code for data size, data copy, and computations

2.3 RedSim benchmarks

Benchmark architectures

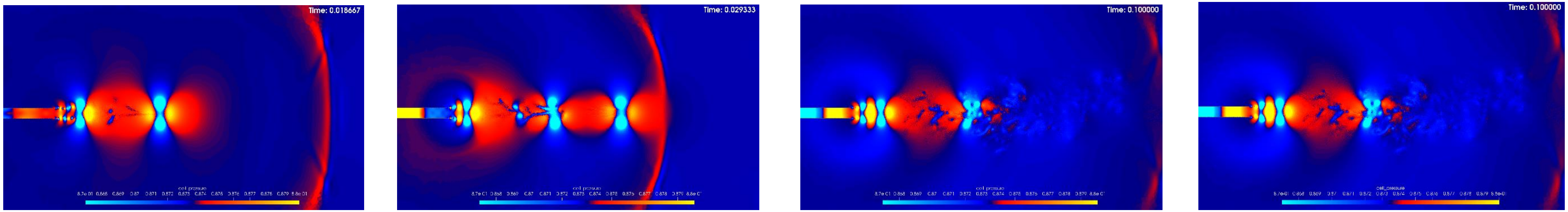
1. Solyom local cluster
    1. 1x FAT node, #CPU-cores = 80, RAM = 3TB
    2. 1x V100s NVIDIA GPU
2. Komondor HPC-machine of the EuroHPC Hungarian National Competence Center KIFÜ
    1. 1x GPU-node with 8x A100 NVIDIA

Benchmark problems

1. Exhaust pipe acoustics problem – for FOM
    1. Origin: industrial problem from automotive industry
    2. #cells = 70M, d.o.f. = 350M
    3. Simulated time (physical time): 1.0 sec
2. Urban air flow computation for the city of Gyor – for FOM and ROM
    1. Small mesh: #cells = 1.4M (d.o.f. = 7M) (spatial resolution: 5 m) (Remark: 1 state vector = 100 MB)
    2. Medium mesh: #cells = 18M (d.o.f. = 90M) (spatial resolution: 2 m) (Remark: 1 state vector = 1 GB)

Benchmark problem 1: Exhaust pipe acoustics problem

1. Runtime: 6 hours with the multi-GPU version, video: https://www.youtube.com/watch?v=rAKsChm9-b8



2. Validation to measurements

Comparison: AUDI measurements / SZE results.

Evaluated Time: [0.1s, 0.4s]

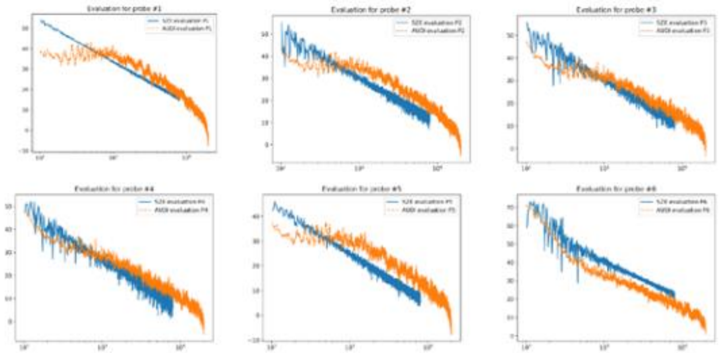


Figure 5: Comparison between the measured SPL values for the straight-pipe provided by the industrial partner (see [3]), and the simulated SPL values by SZE.

2.3 RedSim benchmarks

Table 1. Parallel efficiency for the 2D SOD Shock Tube Problem with N = 16,000,000 squares as cells. *P* denotes the number of GPUs.

EFFICIENCY	KOMONDOR 8x NVIDIA A100-SXM4-40GB	VEGA 4x NVIDIA A100-SXM4-40GB
P=1	1	1
P=2	0.968994657	0.9772293065
P=4	0.9142748011	0.9205859105
P=8	0.7212876395	NO DATA

Table 2. Parallel efficiency for the 2D SOD Shock Tube Problem with N = 64,000,000 squares as cells. *P* denotes the number of GPUs.

EFFICIENCY	KOMONDOR 8x NVIDIA A100-SXM4-40GB	VEGA 4x NVIDIA A100-SXM4-40GB
P=1	1	1
P=2	0.9897779737	0.9930057839
P=4	0.9706092646	0.9753116722
P=8	0.9105837686	NO DATA

Table 3. Parallel efficiency for the 3D Gyor airflow problem with N = 18,342,623 tetrahedra as cells. *P* denotes the number of GPUs.

EFFICIENCY	KOMONDOR 8x NVIDIA A100-SXM4-40GB	VEGA 4x NVIDIA A100-SXM4-40GB
P=1	1	1
P=2	0.9225121646	0.9742910708
P=4	0.8208693259	0.9753116722

Video: https://www.youtube.com/watch?v=-pJAISsKJHQ

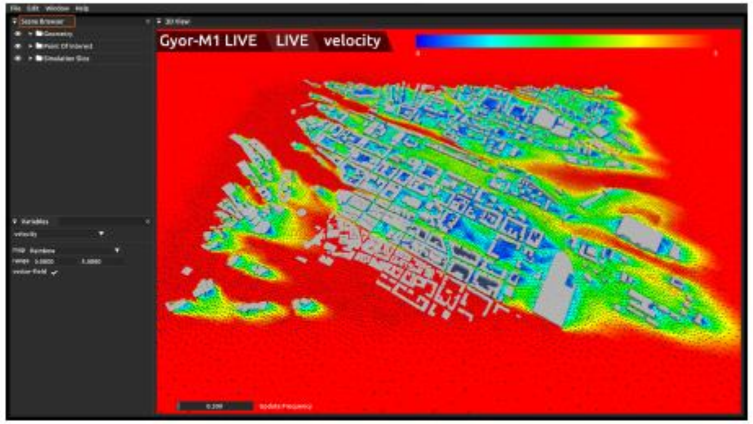
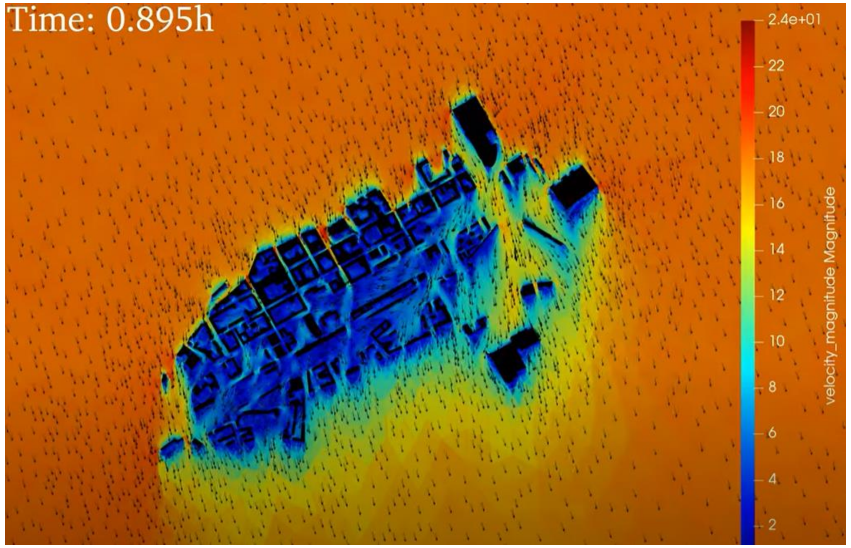


Fig. 1. Live visualization of the HPC-computations.

2.3 RedSim benchmarks



Benchmark problem 2.2: Urban air flow, #cells=18M

1. Video: https://www.youtube.com/watch?v=-pJAISsKJHQ

2. Runtimes, and parallel scalability: 82% on p=4 GPUs (i.e. more than 3 times faster on 4 GPU than on 1 GPU)

Wall-Clock Time: Urban Airflow, Gyor. **N = 18342623**			
wall-clock (s)	ONDOR, 4x NVIDIA A100-SXM4-4	, 4x NVIDIA A100-SXM4-	SOLYOM, 1x NVIDIA Tesla V100S-PCIE-32GB
P = 1	2781.590725	2783.904732	2127.01869
P = 2	1507.617369	1428.682257	NO DATA
P = 4	847.147846	1475.724026	NO DATA
Wall-Clock Time: Urban Airflow, Gyor. **N = 3154126**			
wall-clock (s)	**KOMONDOR**	**VEGA**	**SOLYOM**, 1x NVIDIA Tesla V100S-PCIE-32GB
P = 1	432.583269	433.15866	276.966294
P = 2	271.443758	234.848385	NO DATA
P = 4	182.695222	269.181903	NO DATA

Efficiency: Urban Airflow, Gyor. **N = 30,291,099**		
efficiency	**KOMONDOR**, 4x NVIDIA A100-SXM4-40GB	**VEGA**, 4x NVIDIA A100-SXM4-40GB
P = 1	1	-
P = 2	0.9449242544	-
P = 4	0.8752212861	-

Efficiency: Urban Airflow, Gyor. **N = 18,342,623**		
efficiency	KOMONDOR, 4x NVIDIA A100-SXM4-40GB	VEGA, 4x NVIDIA A100-SXM4-40GB
P = 1	1	1
P = 2	0.9225121646	0.9742910708
P = 4	0.8208693259	0.4716167595

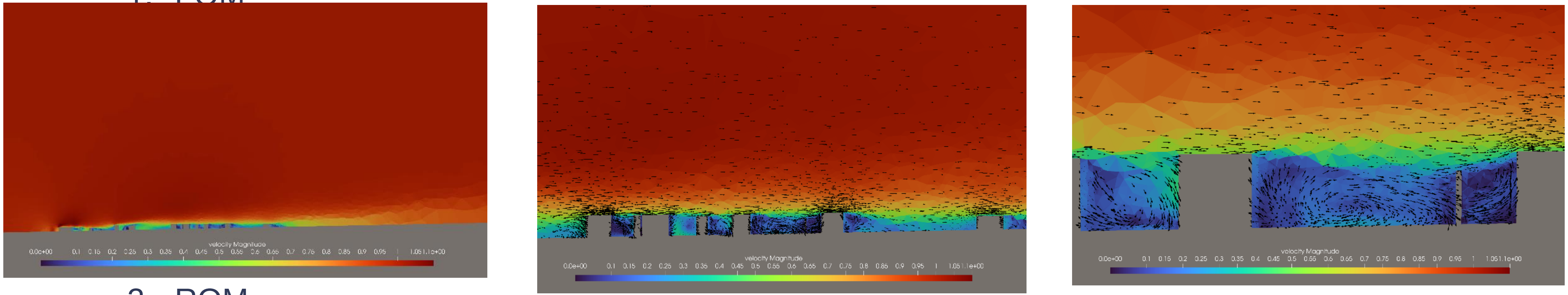
Efficiency: Urban Airflow, Gyor. **N = 3,154,126**		
efficiency	KOMONDOR, 4x NVIDIA A100-SXM4-40GB	VEGA, 4x NVIDIA A100-SXM4-40GB
P = 1	1	1
P = 2	0.7968193341	0.9222091521
P = 4	0.5919466096	0.4022917729

2.3 Redsim benchmarks: FOM vs ROM

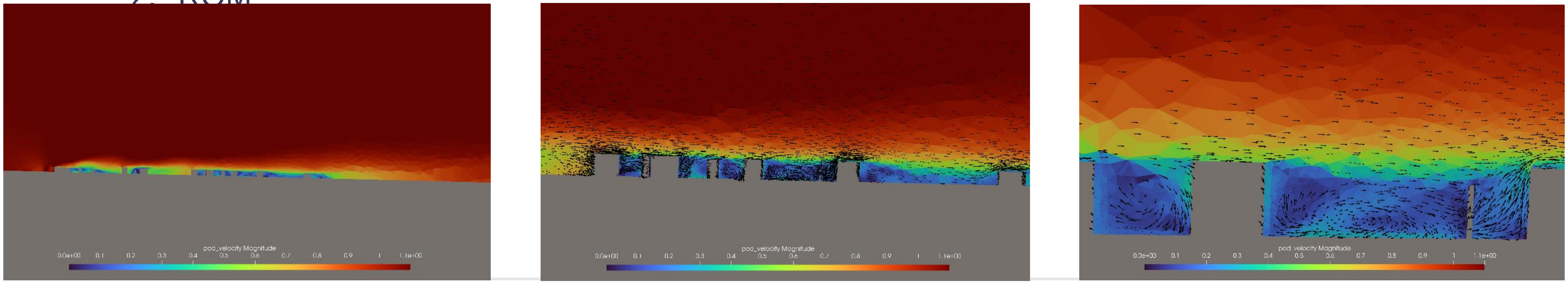
Benchmark problem 2.2: Urban air flow, #cells=18M

3. Visual comparision of FOM and ROM with eta = 85%; video: https://youtu.be/wTGuYMlmFcE (#cells=1.4M)

1. FOM



2. ROM



2.3 RedSim benchmarks: FOM vs. ROM

Benchmark problem 2.2: Urban air flow

ETA + (1, 2, 2, 5, 1)	r	CFL	rho	rho v1	rho v2	rho v3	e	V100 GPU runtime (seconds)
100%	(100, 100, 100, 100 ,100)	25	0.00232	0.05780	0.07466	0.20311	0.00313	95.83356
99%	(2, 63, 63, 84, 2)	50	0.00021	0.06854	0.07245	0.18365	0.00011	31.20451
98%	(2, 48, 48, 72, 2)	60	0.00036	0.06847	0.07175	0.18855	0.00021	27.59252
95%	(2, 26, 27, 51, 2)	60	0.00031	0.07146	0.07409	0.19842	0.00017	21.91905
90%	(2, 13, 13, 35, 2)	60	0.00150	0.07298	0.06699	0.19363	0.00265	18.16461
80%	(2, 6, 6, 20, 2)	60	0.01023	0.11446	0.15723	0.18984	0.01157	15.54122
70%	(2, 4, 4, 13, 2)	100	0.02326	0.20657	0.32415	0.28957	0.02581	7.50004
60%	(2, 3, 3, 10, 2)	100	0.02158	0.21504	0.32845	0.31873	0.01073	7.31519
50%	(2, 3, 3, 8, 2)	100	0.02190	0.21563	0.33013	0.31821	0.01151	7.20283
40%	(2, 3, 3, 7, 2)	100	0.02252	0.21503	0.33032	0.31542	0.01251	7.17410
20%	(2, 3, 3, 6, 2)	100	0.02206	0.21370	0.32785	0.31684	0.01176	7.12716

N = 18342623 , t = 3600s, ||v||=1m/s Static Wind (80 deg), REDUCED DOMAIN, L1 ERROR MEDIAN FROM 11 DIFF TIME POINTS

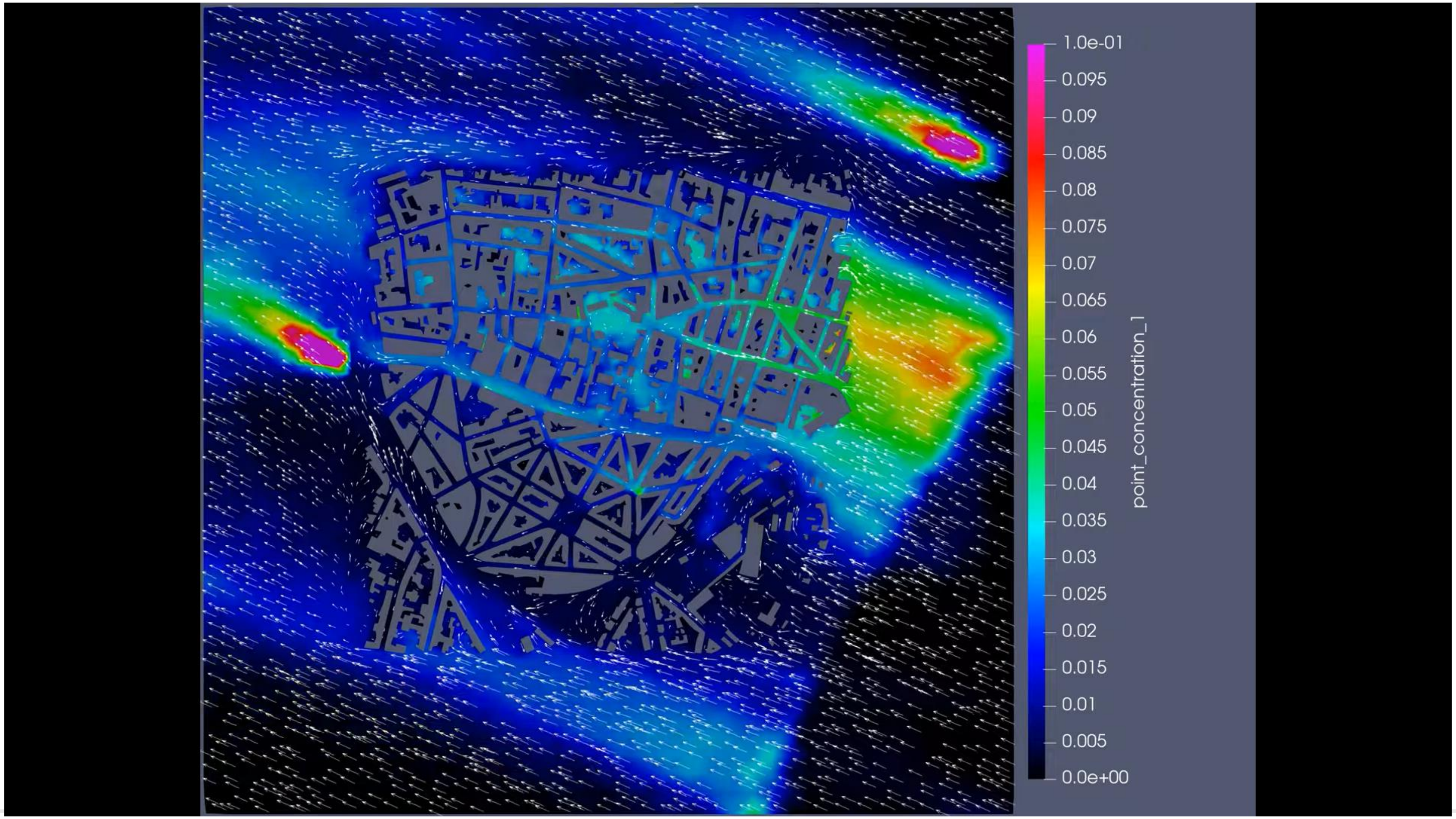
ETA + (1, 2, 2, 5, 1)	r	CFL	rho	rho v1	rho v2	rho v3	e	V100 GPU runtime (seconds)
85%	(2, 39, 39, 56, 2)	25	0.013936	0.175821	0.179983	0.439115	0.017311	979.648389
85%	(2, 39, 39, 56, 2)	50	0.01398	0.17586	0.18003	0.43916	0.01733	494.295947
80%	(2, 28, 28, 45, 2)	50	0.00922	0.17070	0.17400	0.43124	0.01314	440.468834
70%	(2, 14, 14, 29, 2)	100	0.00594	0.16619	0.15655	0.40173	0.01383	188.047495
60%	(2, 8, 8, 19, 2)	100	0.01509	0.19095	0.18687	0.51170	0.00099	168.482461
20%	(2, 3, 3, 7, 2)	100	0.08093	0.25193	0.28858	0.43526	0.01737	154.073113

Physical time: 3,600s		**Runtime for #cells=1.4M:**			**Runtime for #cells=18M:**	
		FOM	712.85s		**FOM**	13,723.79s
		POD eta=90%	18.16s		**POD eta=85%**	494.30s

3. Conclusions 1

NOx concentration propagation in Antwerp for **1 full year**, FAIRMODE intercomparison exercise.

Link: https://www.youtube.com/watch?v=sikD2pbpS9A

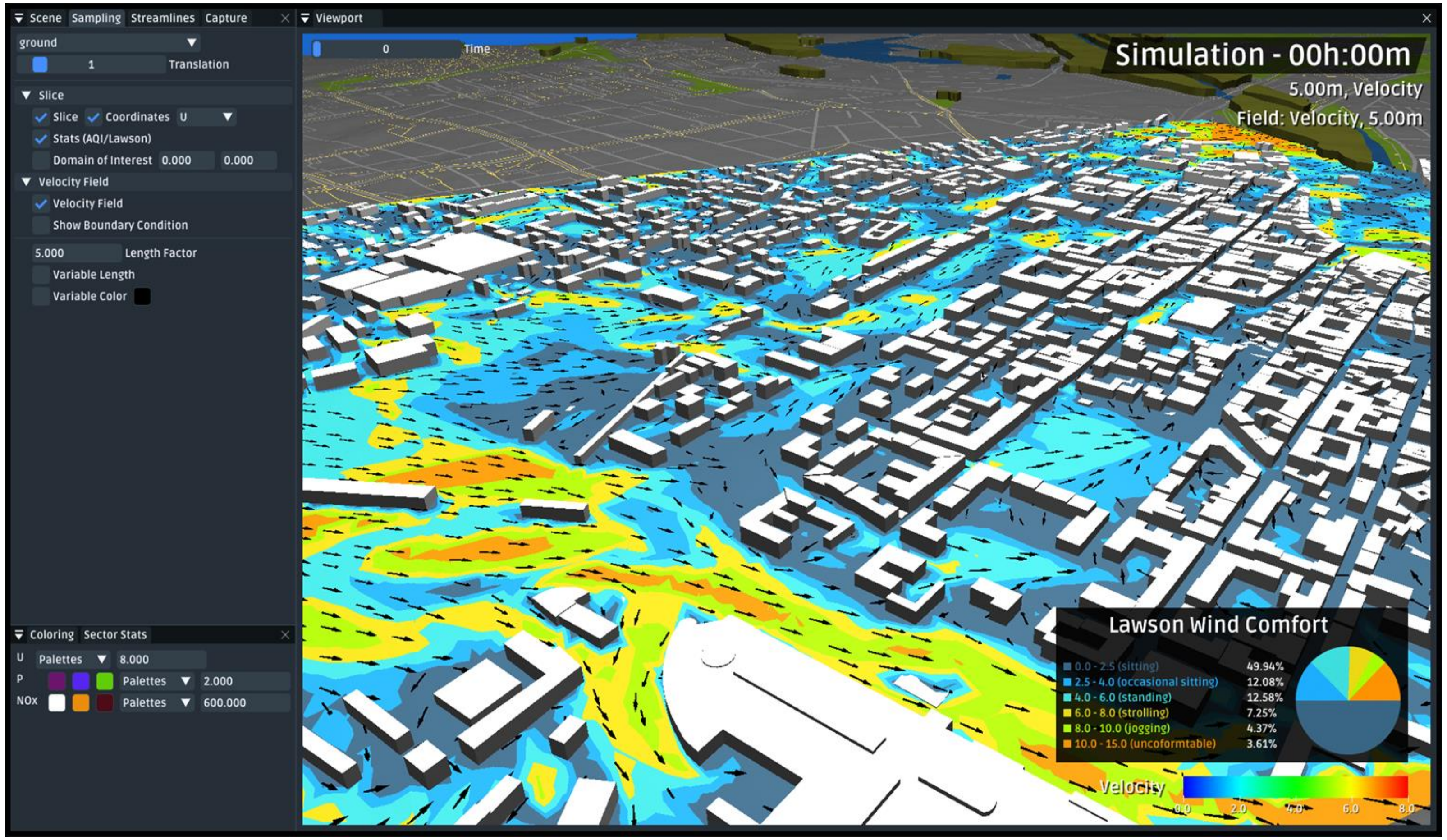


3. Conclusions 2

Real-time digital twin prototype for the airflow for the city of Győr

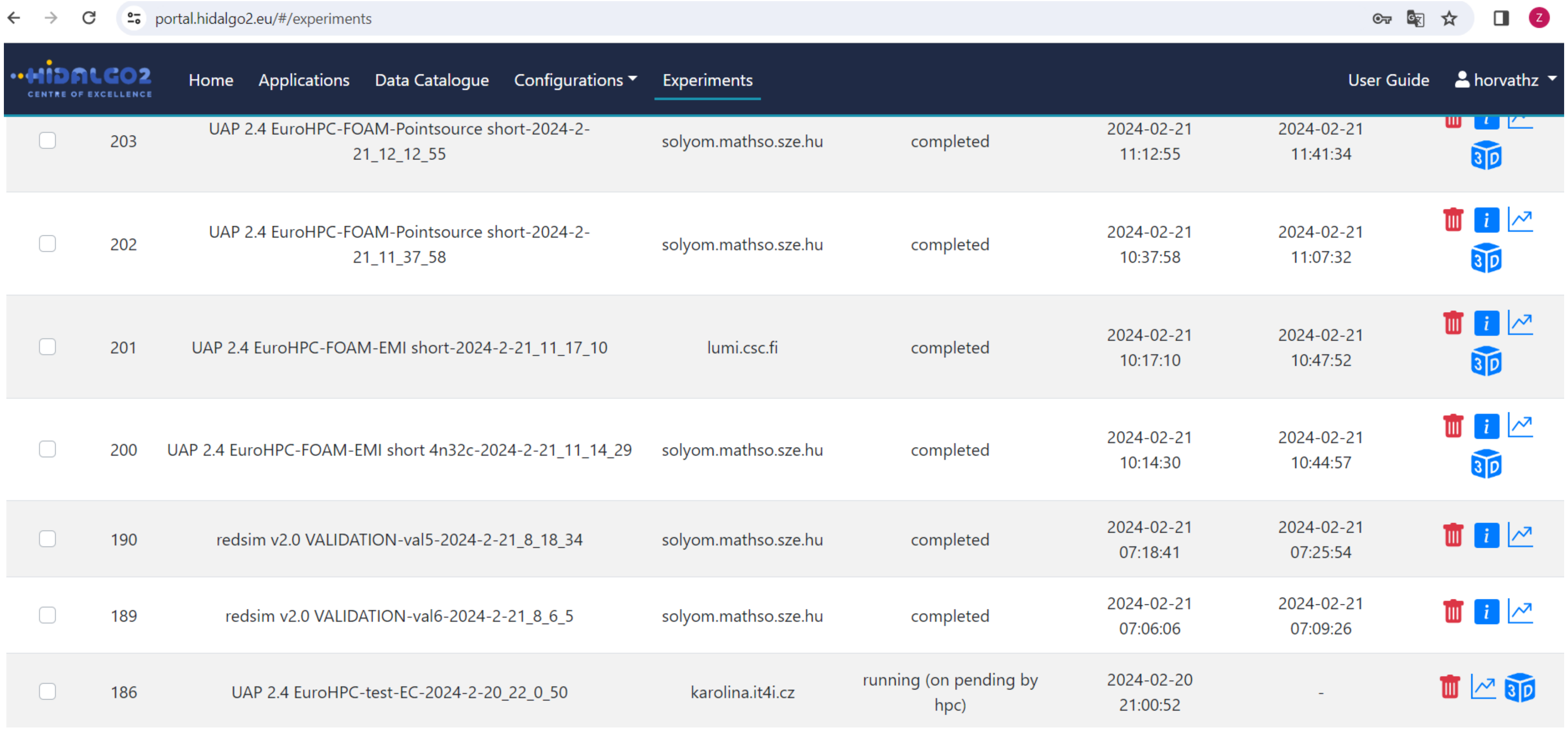
3. Conclusions 3

Real-time HPC + HPDA (Lawson wind comfort)



3. Conclusions 4: UAP from the portal

https://portal.hidalgo2.eu/



☐	203	UAP 2.4 EuroHPC-FOAM-Pointsource short-2024-2-21_12_12_55	solyom.mathso.sze.hu	completed	2024-02-21 11:12:55	2024-02-21 11:41:34	3D
☐	202	UAP 2.4 EuroHPC-FOAM-Pointsource short-2024-2-21_11_37_58	solyom.mathso.sze.hu	completed	2024-02-21 10:37:58	2024-02-21 11:07:32	i 3D
☐	201	UAP 2.4 EuroHPC-FOAM-EMI short-2024-2-21_11_17_10	lumi.csc.fi	completed	2024-02-21 10:17:10	2024-02-21 10:47:52	i 3D
☐	200	UAP 2.4 EuroHPC-FOAM-EMI short 4n32c-2024-2-21_11_14_29	solyom.mathso.sze.hu	completed	2024-02-21 10:14:30	2024-02-21 10:44:57	i 3D
☐	190	redsim v2.0 VALIDATION-val5-2024-2-21_8_18_34	solyom.mathso.sze.hu	completed	2024-02-21 07:18:41	2024-02-21 07:25:54	i
☐	189	redsim v2.0 VALIDATION-val6-2024-2-21_8_6_5	solyom.mathso.sze.hu	completed	2024-02-21 07:06:06	2024-02-21 07:09:26	i
☐	186	UAP 2.4 EuroHPC-test-EC-2024-2-20_22_0_50	karolina.it4i.cz	running (on pending by hpc)	2024-02-20 21:00:52	-	3D

3. Further work for the next year

1. RedSim
    1. Co-design: Optimization of RedSim for special hardware (e.g. support tetrahedral mesh only) – we expect significantly (maybe 100x) faster code than the current multi-GPU code for polyhedral meshes
    2. MPI + Multi-GPU with CUDA and then with OpenCL
    3. Develop implicit time-stepping and an operational real-time digital twin for urban airflow
2. More physics
    1. A more detailed atmosphere model, coupled with WRF
    2. Couple with other HiDALGO2 use-cases
        1. Urban Building Model
        2. waLBerla for small particle propagation
        3. WildFIRES
3. Couple with the Destination Earth platform
4. Collaborations with UAP in EuroHPC: GPU-porting,
5. Services with UAP for the environmental sector and the general industry

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KIFÜ

Thank you for your attention

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