Development of Numerical Coupled Analysis Method by Air Flow Analysis and Snow Accretion Analysis

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Motivation and Objective

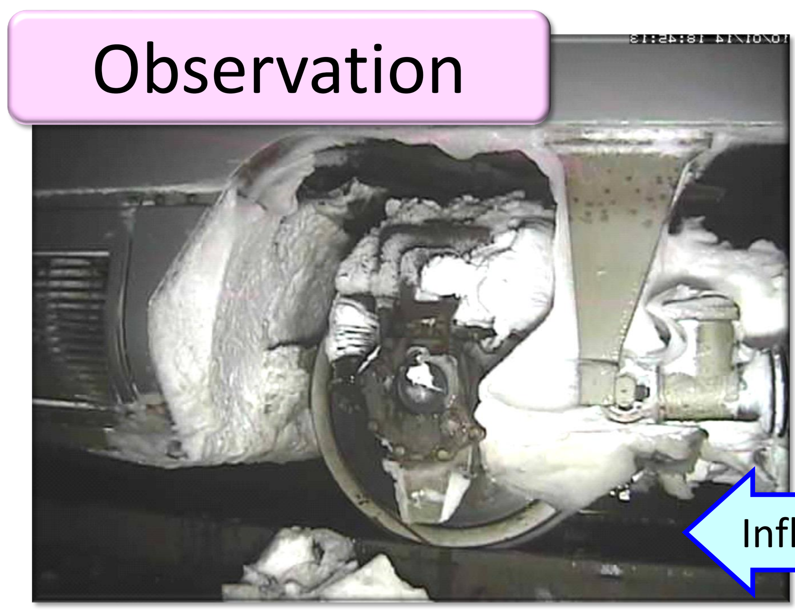
Our research is about snow accretion on a train. The train travels over snow covered tracks, snow accretes to train bogies. When the accreted snow dropped off from train bogies, they might damage the railway ground facilities along the tracks, the train devices, etc.

To establish countermeasures against the damage, we have developed a snow accretion simulator. By performing snow accretion analysis for various modified train shape, we will find the train shape which reduces the amount of accreted snow.

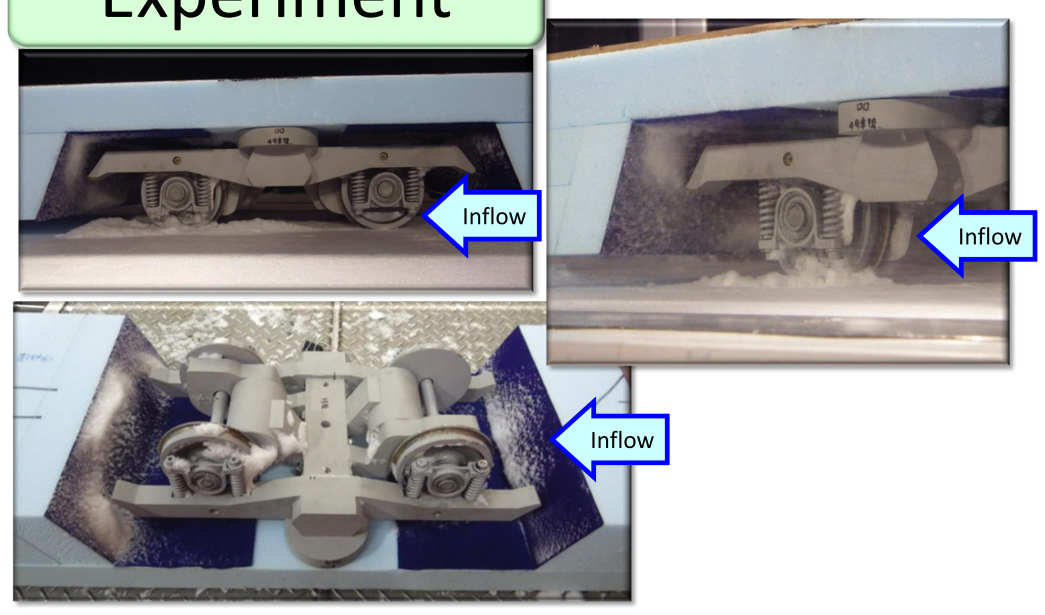
Our aim

We have validated the results obtained from our snow accretion by comparing them with those obtained from the experiments by the use the snowfall wind tunnel. Additionally, since this snow accretion simulator is made by the distributed memory parallel calculation programing, it allows us to solve a very huge calculation model such as a whole train bogie.

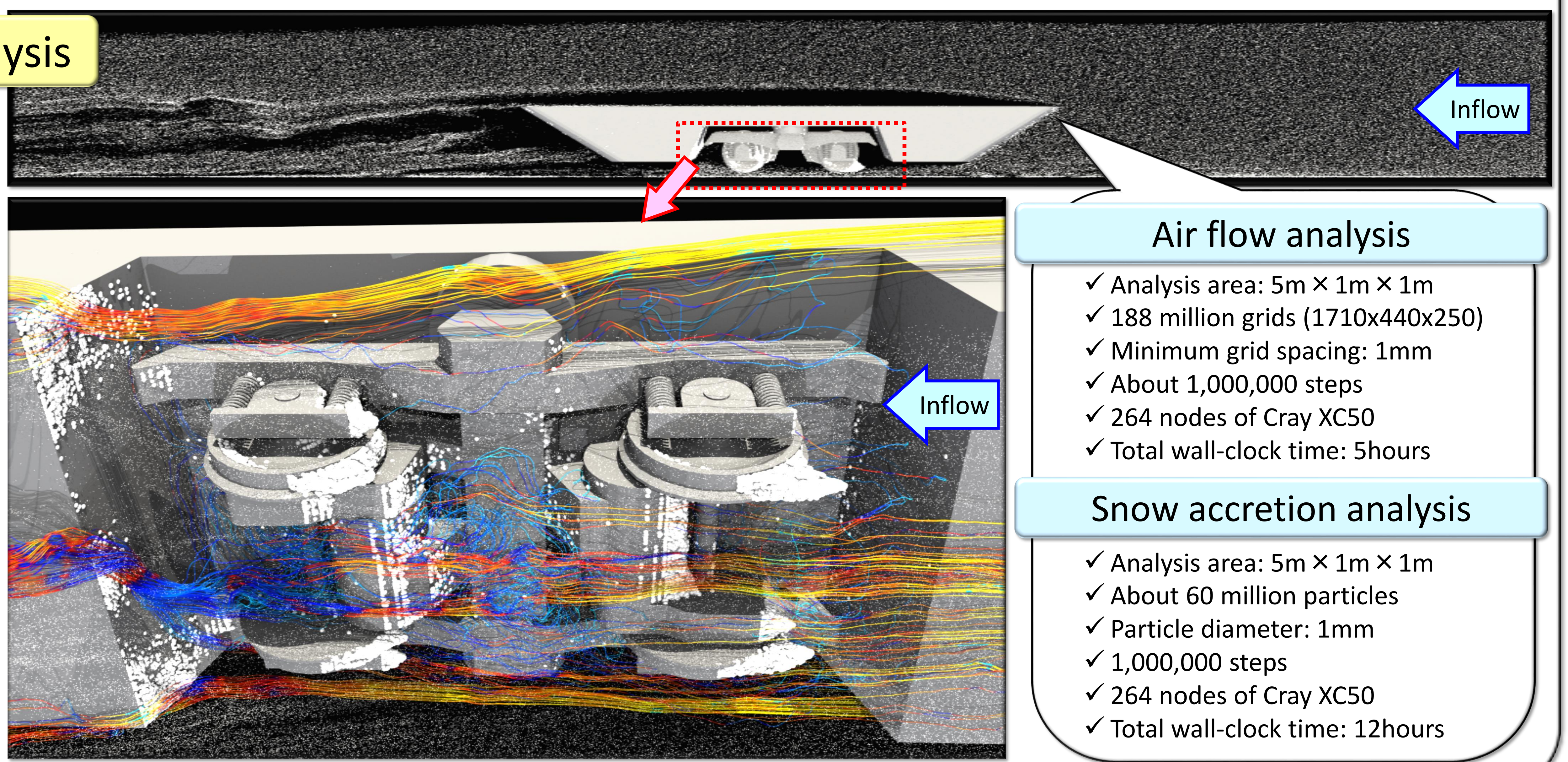
Observation



Experiment



Analysis



Air flow analysis

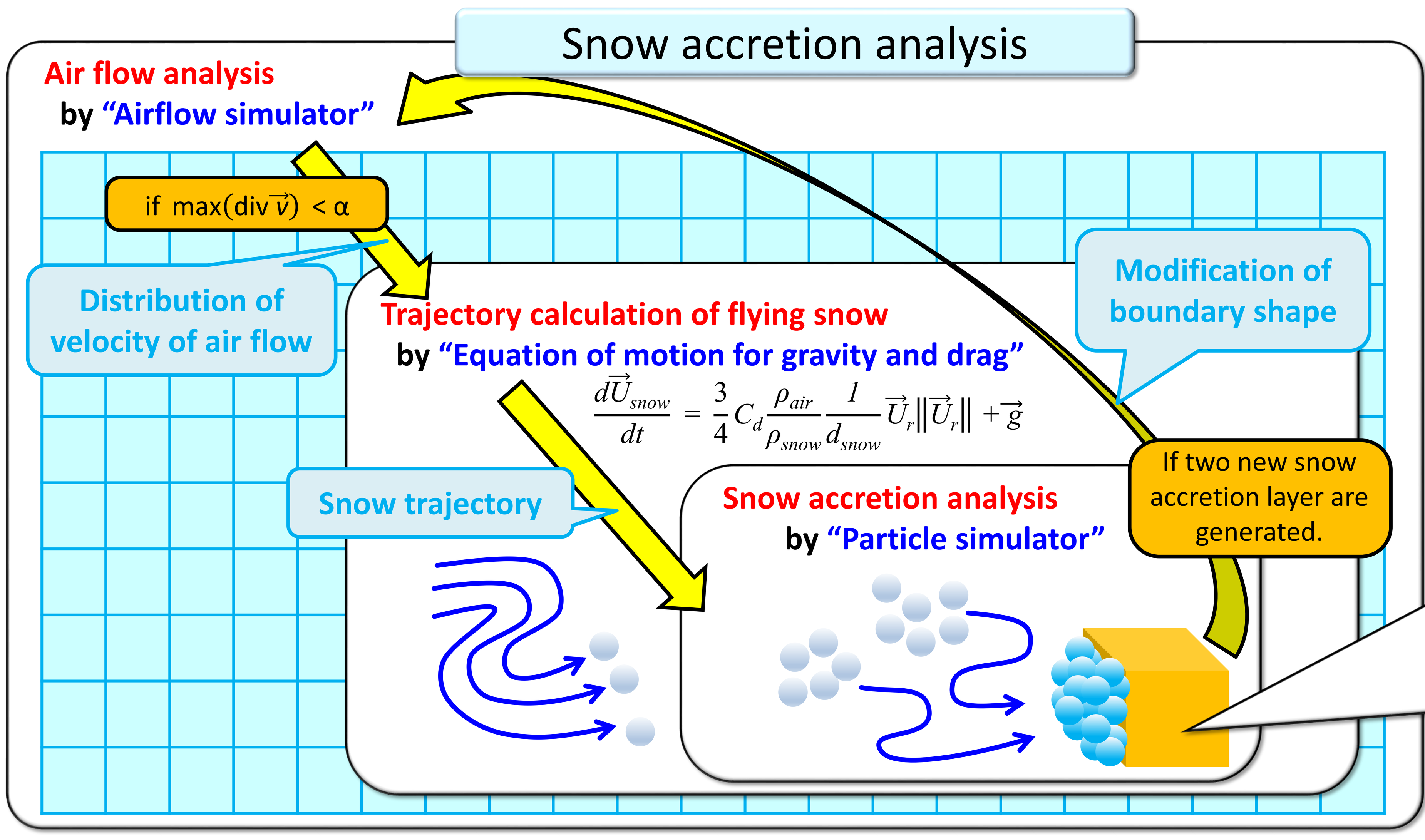
- ✓ Analysis area: 5m × 1m × 1m
- ✓ 188 million grids (1710x440x250)
- ✓ Minimum grid spacing: 1mm
- ✓ About 1,000,000 steps
- ✓ 264 nodes of Cray XC50
- ✓ Total wall-clock time: 5hours

Snow accretion analysis

- ✓ Analysis area: 5m × 1m × 1m
- ✓ About 60 million particles
- ✓ Particle diameter: 1mm
- ✓ 1,000,000 steps
- ✓ 264 nodes of Cray XC50
- ✓ Total wall-clock time: 12hours

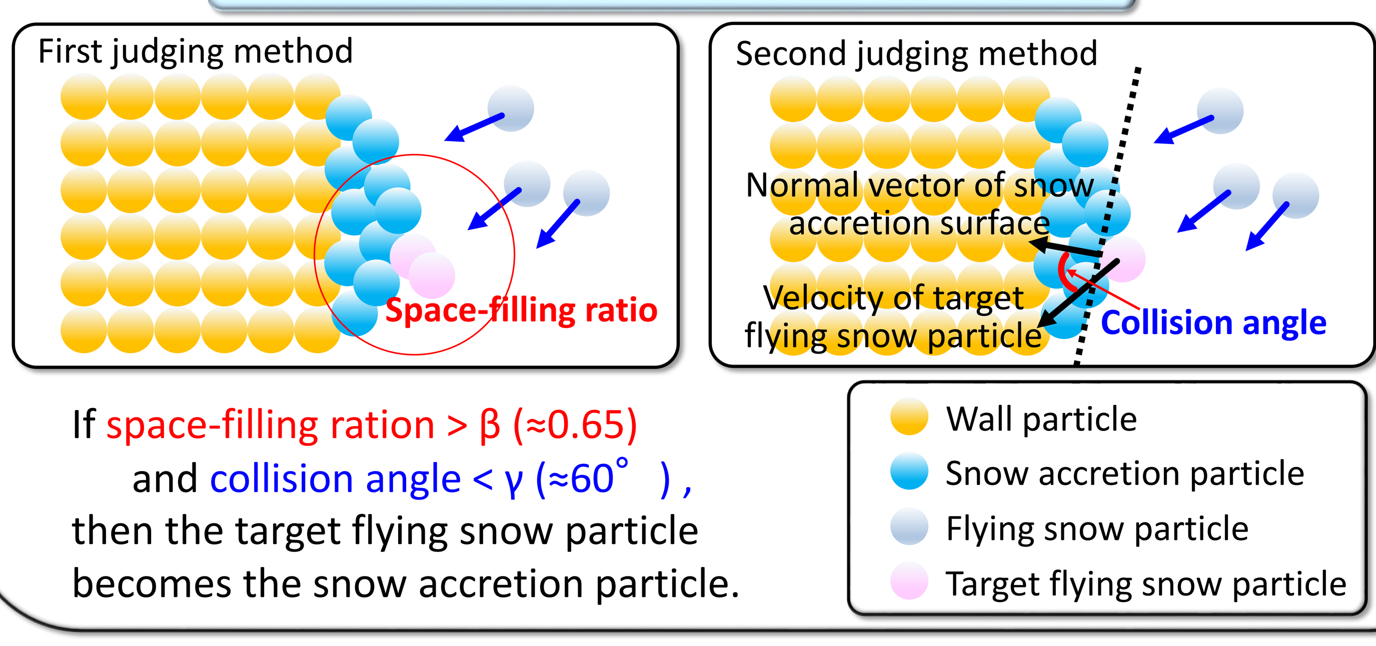
Numerical Coupled Analysis Method by Air Flow Analysis and Snow Accretion Analysis

Snow accretion analysis



The experiment team realizes the observed actual phenomenon for simple and small model using the snowfall wind tunnel. The analysis team develops the snow accretion analysis method using Cartesian grid methods and particle method. The developed snow accretion simulator is validated by trial and error with the experiment using simple and small models.

Snow accretion algorithm



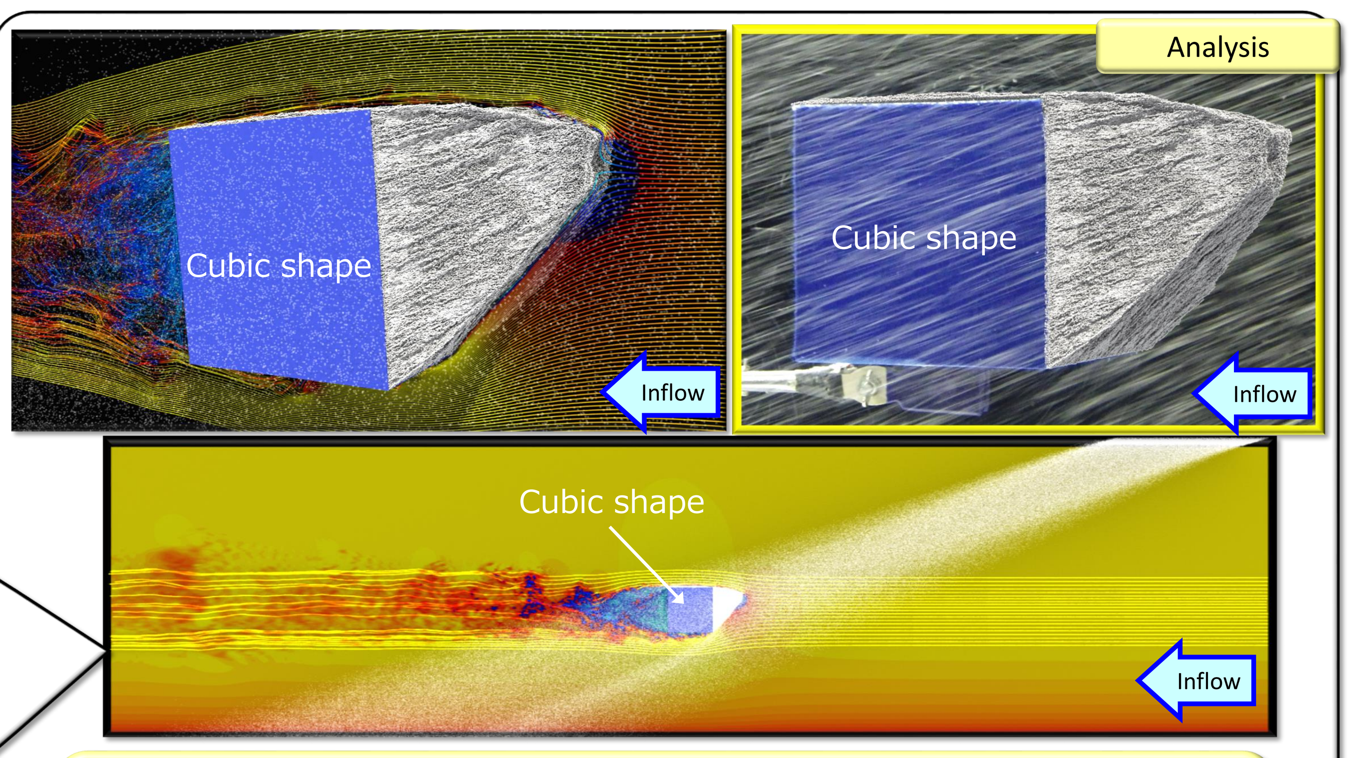
If space-filling ration > β (≈0.65) and collision angle < γ (≈60°), then the target flying snow particle becomes the snow accretion particle.

Air flow analysis

- ✓ Analysis area: 4m × 1m × 1m
- ✓ 257million grids (1100x500x500)
- ✓ Minimum grid spacing: 1mm
- ✓ About 1,000,000 steps
- ✓ 264 nodes of Cray XC50
- ✓ Total wall-clock time: 7hours

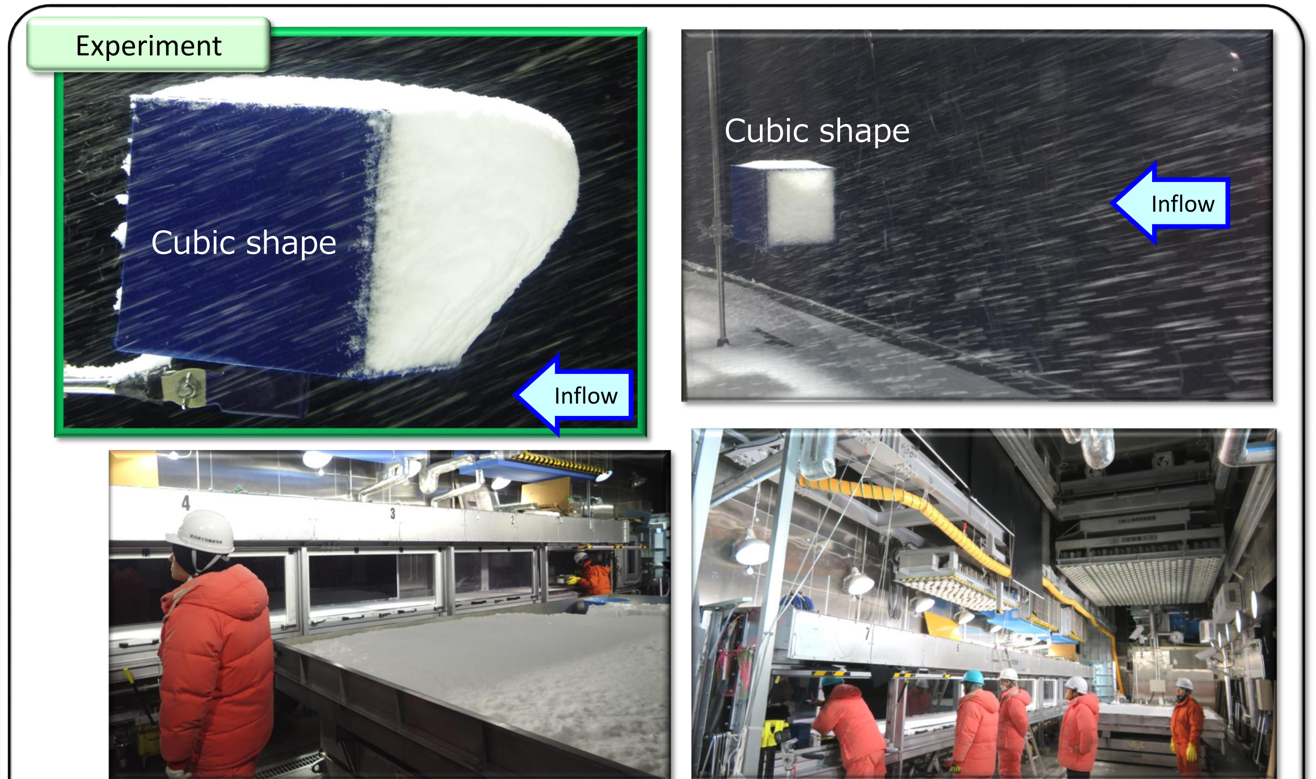
Snow accretion analysis

- ✓ Analysis area: 4m × 1m × 1m
- ✓ About 10 million particles
- ✓ Particle diameter: 1mm
- ✓ 1,000,000 steps
- ✓ 264 nodes of Cray XC50
- ✓ Total wall-clock time: 3hours



Snow accretion analysis and air flow analysis

Transparent particles are flying snow particles. Opacity particles are snow accretion particles. Colors are velocity magnitude of air flow.



Experiment of snow accretion at snowfall wind tunnel

at Snow and Ice Research Center, National Research Institute for Earth Science and Disaster Resilience

Supercomputer used in this research

System	Site	Processor (peak FLOPS)	Nodes
K computer	RIKEN	2.0 GHz SPARC64 VIIIfx, 8-Core (128 GFLOPS)	88,128 (1 CPUs / node)
FX100	Nagoya Univ.	2.2 GHz SPARC64 XIfx, 32-Core (1,126 GFLOPS)	2,880 (1 CPUs / node)
XC50	Railway Technical Research Institute	2.7 GHz Intel Xeon Gold 6150, 18-Core (1,555 GFLOPS)	264 (2 CPUs / node)

ACKNOWLEDGMENTS

This research used computational resources of the K computer provided by the RIKEN Advanced Institute for Computational Science and the FX100 provided by the Nagoya university through the HPCI System Research project (Project ID: hp170067, hp180014). This work was supported by JSPS KAKENHI Grant Number 17K05152.

Airflow simulator

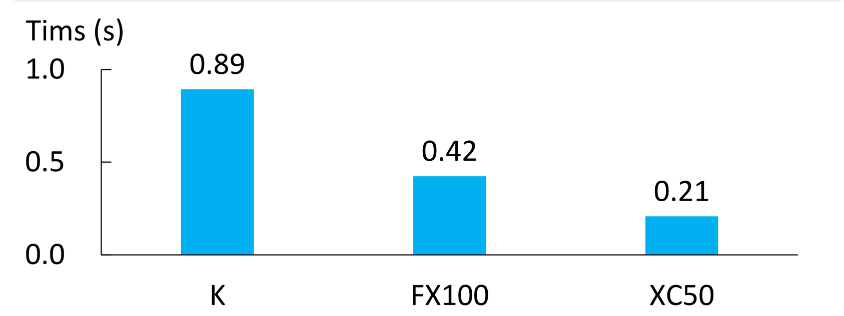
Overview

- Navier-Stokes equation for Incompressible fluid flow
- Finite difference method for nonuniform grid
- Fractional step method
- 2nd-order central difference
- 3rd-order Adams-Bashforth methods
- Poisson equation solver by Jacobi method
- LES model by coherent structure Smagorisky model
- Orthogonal domain decomposition
- Target problem size : 10 million - 100 billion grids
- Compiler : Fortran 90

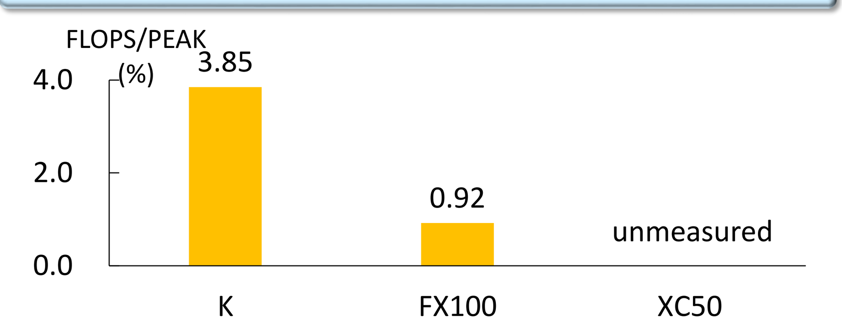
Computational Performances of 100 billion grids by 6,144 nodes

	Elapsed (s)	MFLOPS / PEAK (%)	Memory access throughput / PEAK (%)	SIMD (%)	L1 cache miss (%)	L2 cache miss (%)	TLB miss (%)
	Average				Maximum		
LES model	0.94	5.08	32.04	71.55	4.32	3.22	0.0285
Viscosity and Advection	0.69	4.74	35.95	80.19	4.94	3.24	0.0240
Poisson's equation	2.24	3.71	27.90	15.97	2.89	1.79	0.0007
One Loop	4.44	3.85	29.96	29.75	3.41	2.33	0.0077

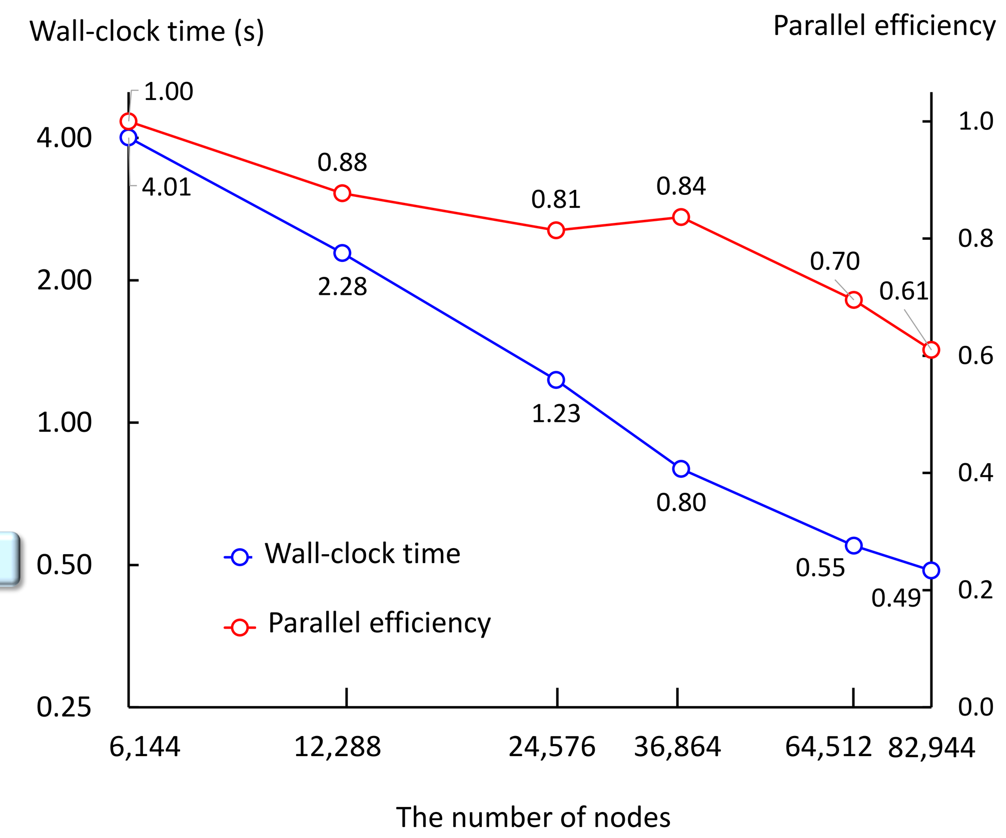
Calculation time of one loop of 42M grids by 12 nodes



FLOPS / PEAK of one loop of 42M grids by 12 nodes



Strong scaling of 100 billion grids by K computer



Particle Simulator

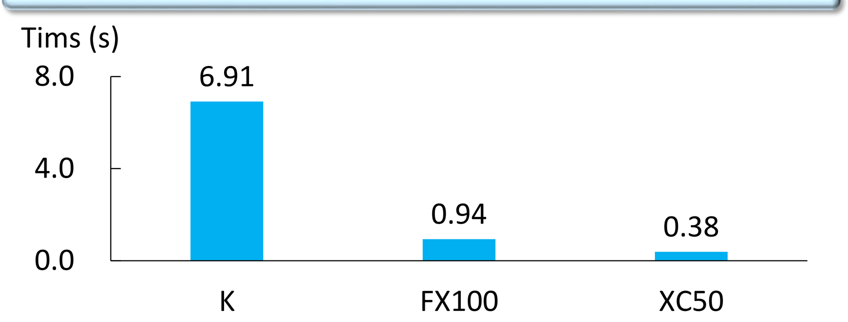
Overview

- Particle simulator by particle interaction
  - Moving Particle Simulation (MPS) method
- Corrosion detection among particles using buckets
- Dynamic load balancing by ParMETIS
- Target problem size : 1 million - 10 billion particles
- Compiler : C

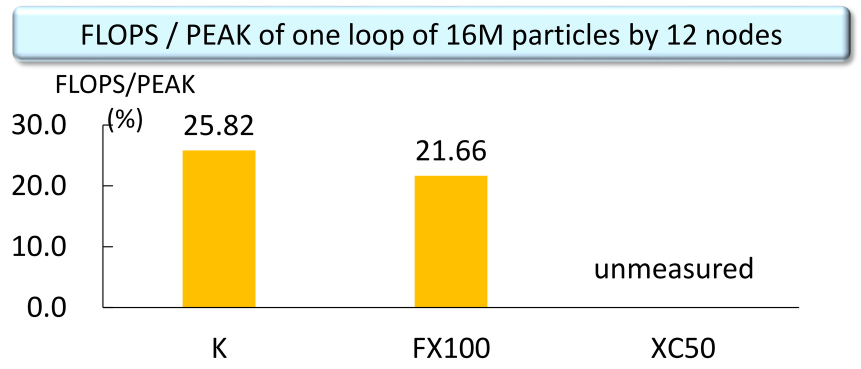
Computational Performances of 10 billion particles by 768 nodes

	Elapsed (s)	MFLOPS / PEAK (%)	Memory access throughput / PEAK (%)	SIMD (%)	L1 cache miss (%)	L2 cache miss (%)	TLB miss (%)
	Average				Maximum		
One loop	0.73	25.8	0.30	49.2	5.09	0.02	0.00

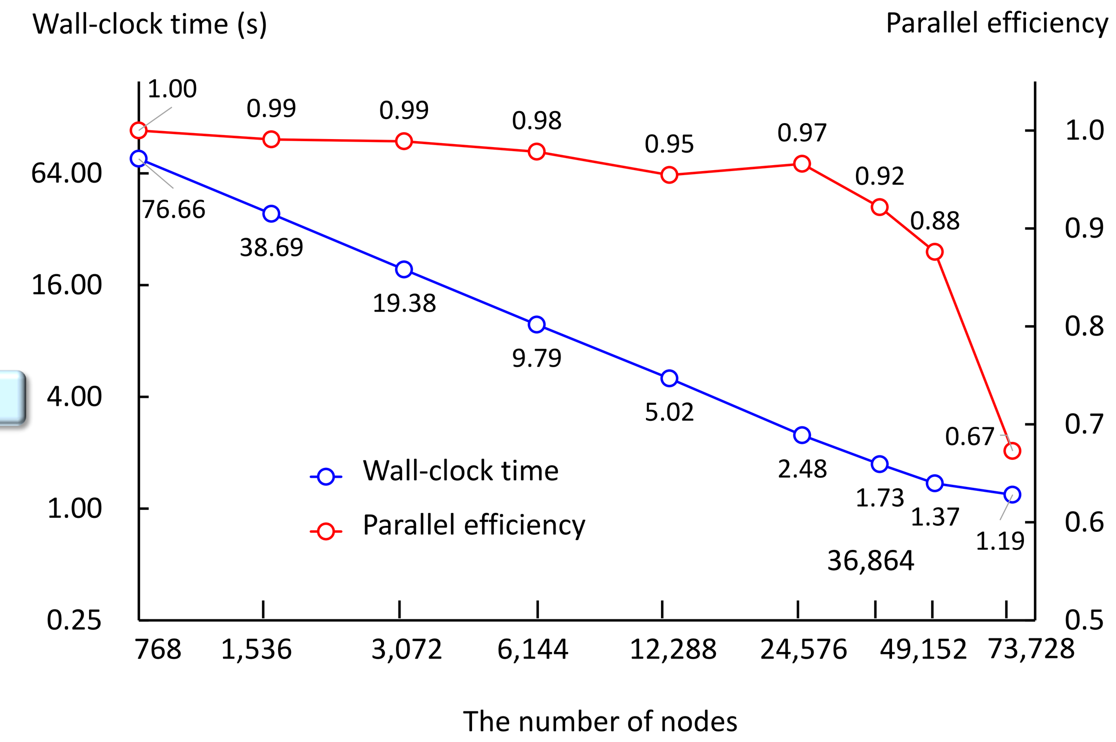
Calculation time of one loop of 16M particles by 12 nodes



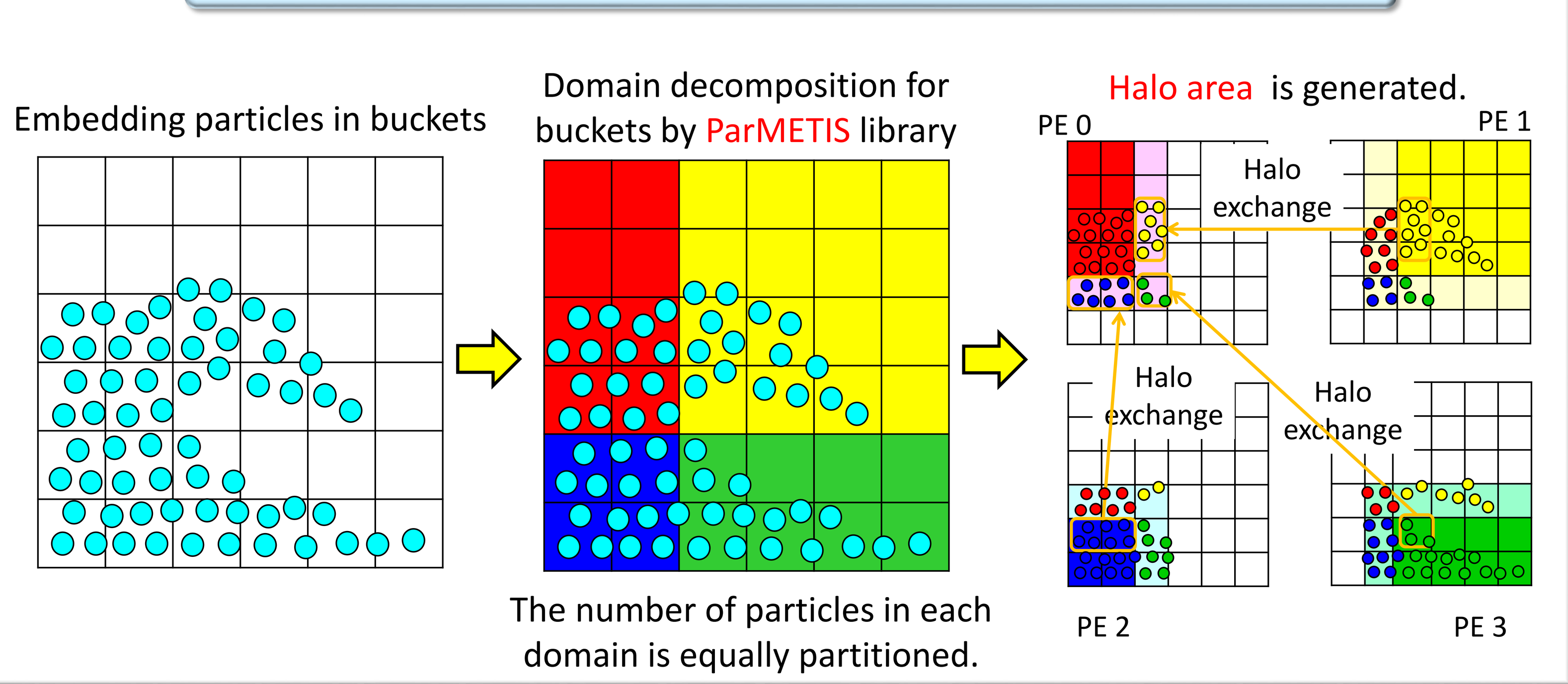
FLOPS / PEAK of one loop of 16M particles by 12 nodes



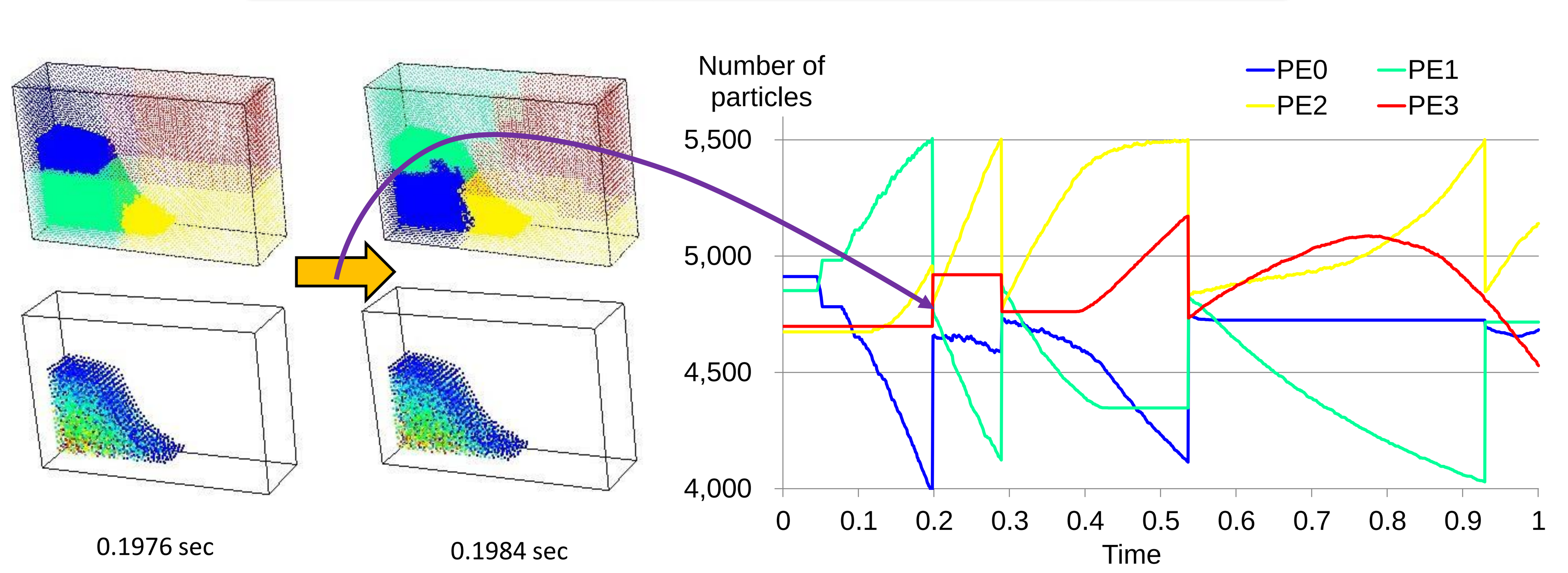
Strong scaling of 10 billion particles by K computer



Domain decomposition and Halo exchange

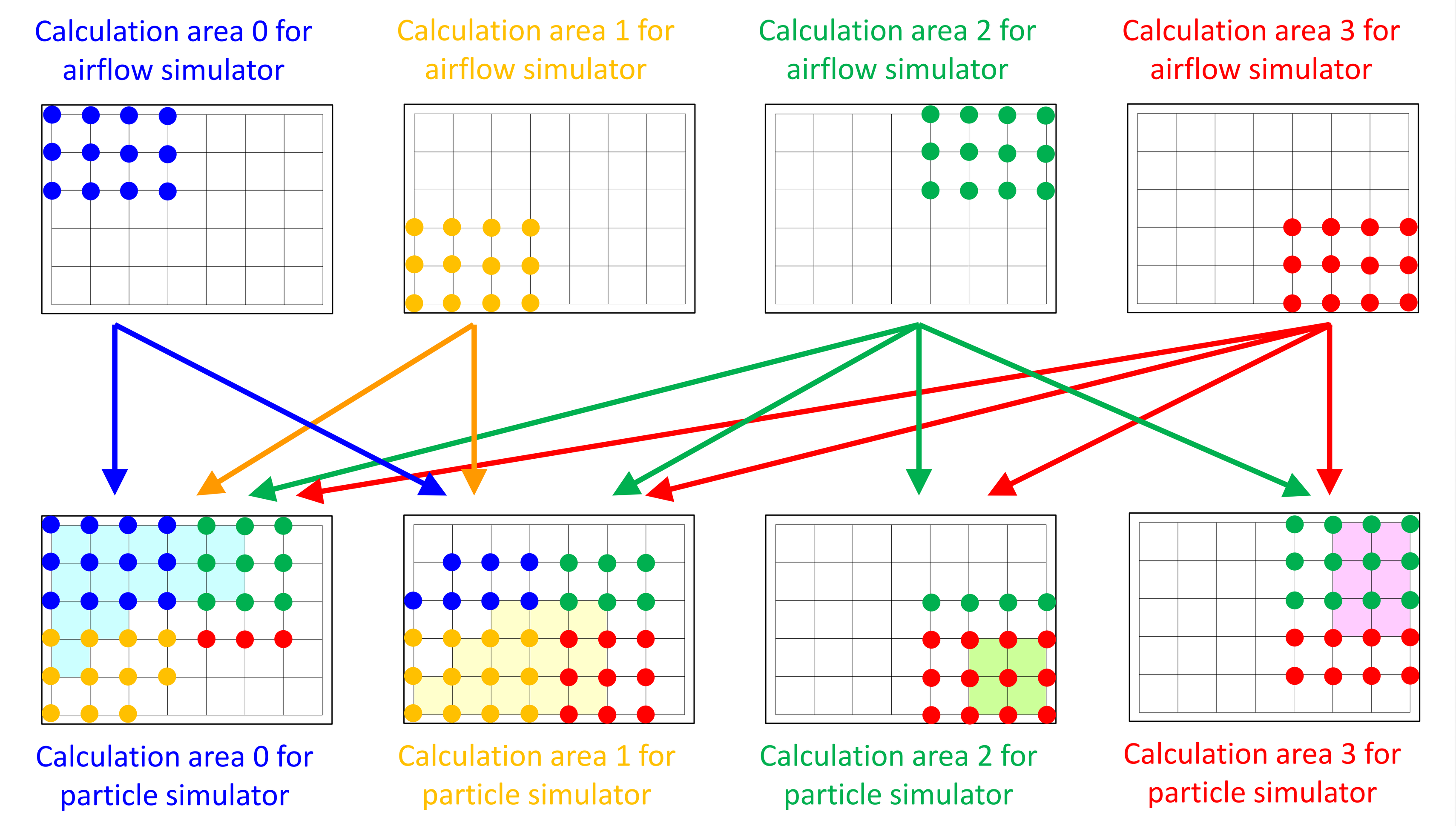


Dynamic load balancing



Communication method between airflow simulator and particle simulator

Communication of velocity distribution from airflow simulator to particle simulator



Communication of boundary shape from particle simulator to airflow simulator