Applications of CFD aided by the high-performance computing platform in the construction industry of Japan

NEC Aurora Forum Webinar in ISC 2022

OBAYASHI CORPORATION
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Agenda

Background

- Continuous development of CFD (Computational Fluid Dynamics) technology dedicated to practical projects in the construction industry since 1980s.
- HPC (High Performance Computing) Platform : NEC SX series
- Dramatical improvement of the performance of computers and advanced technology of CFD to utilize HPC in recent years.

"The rapid expansion of applicability of HPC and its benefits"

Today's Topics

1. The wind load assessment of high-rise buildings
2. The wind climate assessment for offshore wind energy

The wind load assessment of high-rise buildings using CFD on HPC

Topic 1

Wind load assessment and CFD

Wind load assessment of high-rise buildings in Japan

- AIJ Standard (2015) AIJ: Architectural Institute of Japan

  Conventional approach: wind tunnel test

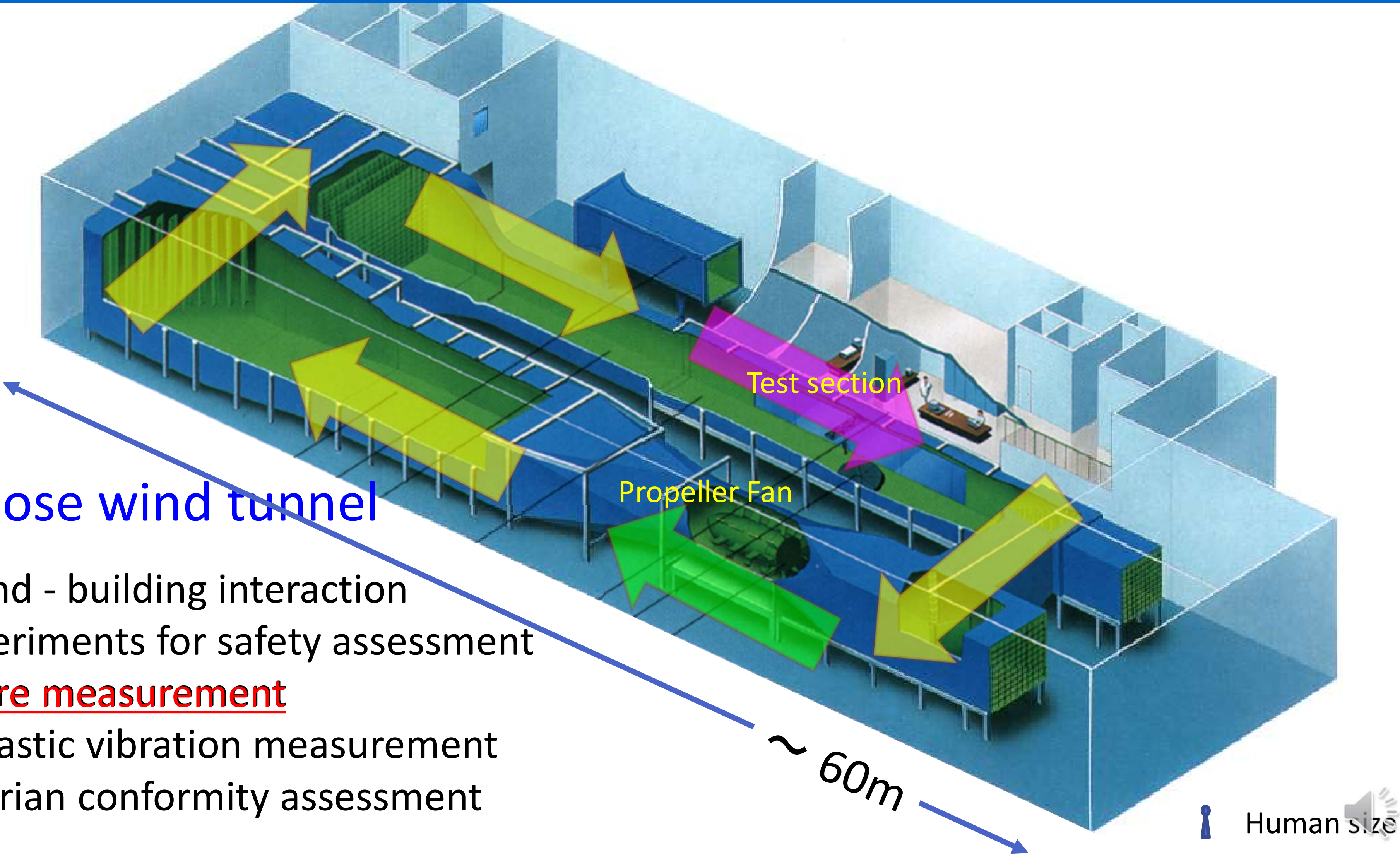
  Emerging capability : CFD

➡

- The rules and regulations to get trustworthy results are currently being discussed.

- Need continuous efforts for improving simulation technology.

Experimental wind tunnel in OBAYASHI



Multi purpose wind tunnel

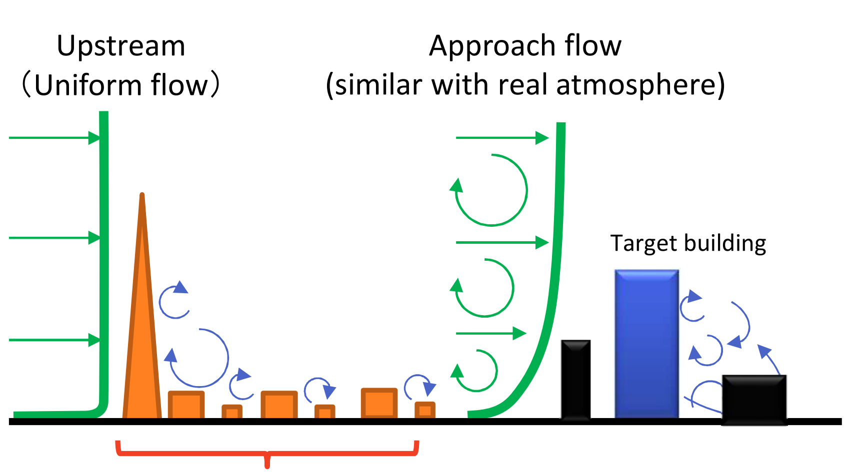
- Examine wind - building interaction
- Type of experiments for safety assessment
  - ✓ <u>Pressure measurement</u>
  - ✓ Aeroelastic vibration measurement
  - ✓ Pedestrian conformity assessment

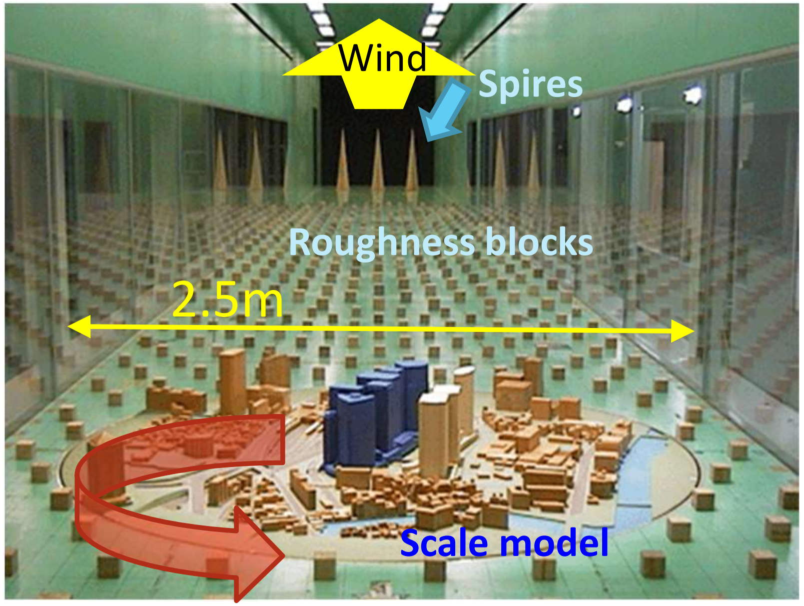
Wind tunnel test for design of buildings

Examination of the interaction between the building model and approaching flow satisfying a couples of similarities.

- Scale model (1/400-1/500) → Geometrical similarity
- Flow structure of approaching flow → Kinematic similarity
- Balancing of dominant forces → Dynamic similarity

Flow structure generation of approach flow





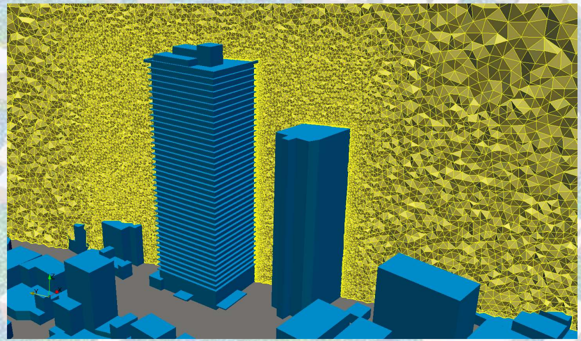
Wind direction : Rotating turning table (the angle of attack)

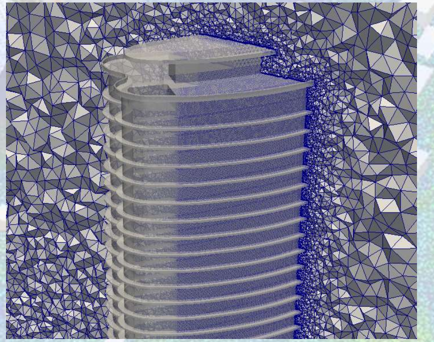
Development of digital wind tunnel in OBAYASHI

DWT = Aerodyna® × Super computers

■「Aerodyna® 」[1] (Fully parallel CFD code)

Solve Navier-Stokes equations numerically and predict the behavior of fluid.





■Super computers

SX ACE in TRI of OBAYASHI

- Vector processors/engines
  - NEC SX-ACE ®

→ Replaced by SX-Aurora TSUBASA ® in Nov. 2021.

1) Ono, "Prediction of Wind Load for Realistic Structure in Urban Area Using Computational Wind Tunnel Aerodynamics", OBAYASHI Tech. Repo., 2015 (In Japanese).

Optimization of fully parallel CFD code for SX-ACE

Unstructured CFD code: “list vector” (indirect address reference) can harm vector performance.
Strategy for optimization : Maximize vectorization rate of the code, utilize scalar processing unit.

10 steps computational time (excluding gray color)

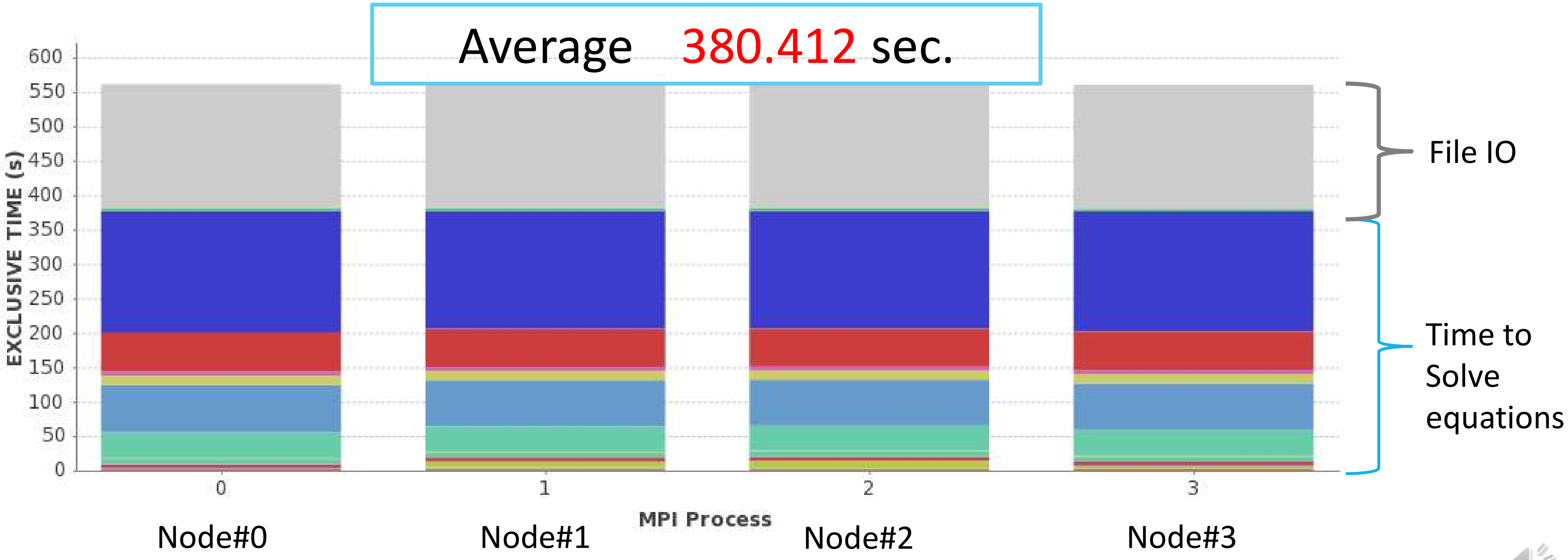


Figure. Computational time per MPI nodes（Before optimization）

Optimization results

Examples of effective optimization for our case

- Keeping stencil length constant in integration loop (for continuous memory access)
- Insertion of "ShortVector" directive to notify the length of vector to the compiler.

10 steps computational time (excluding gray color)

Average 45.886 sec.

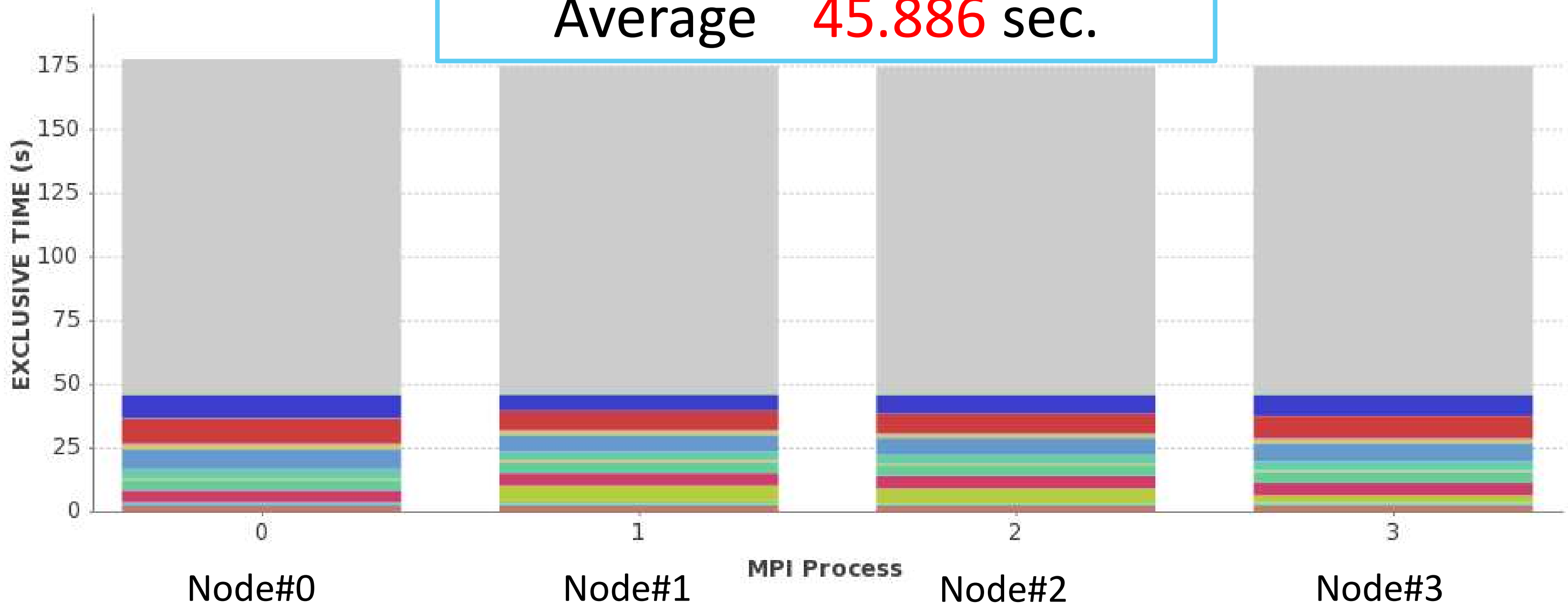
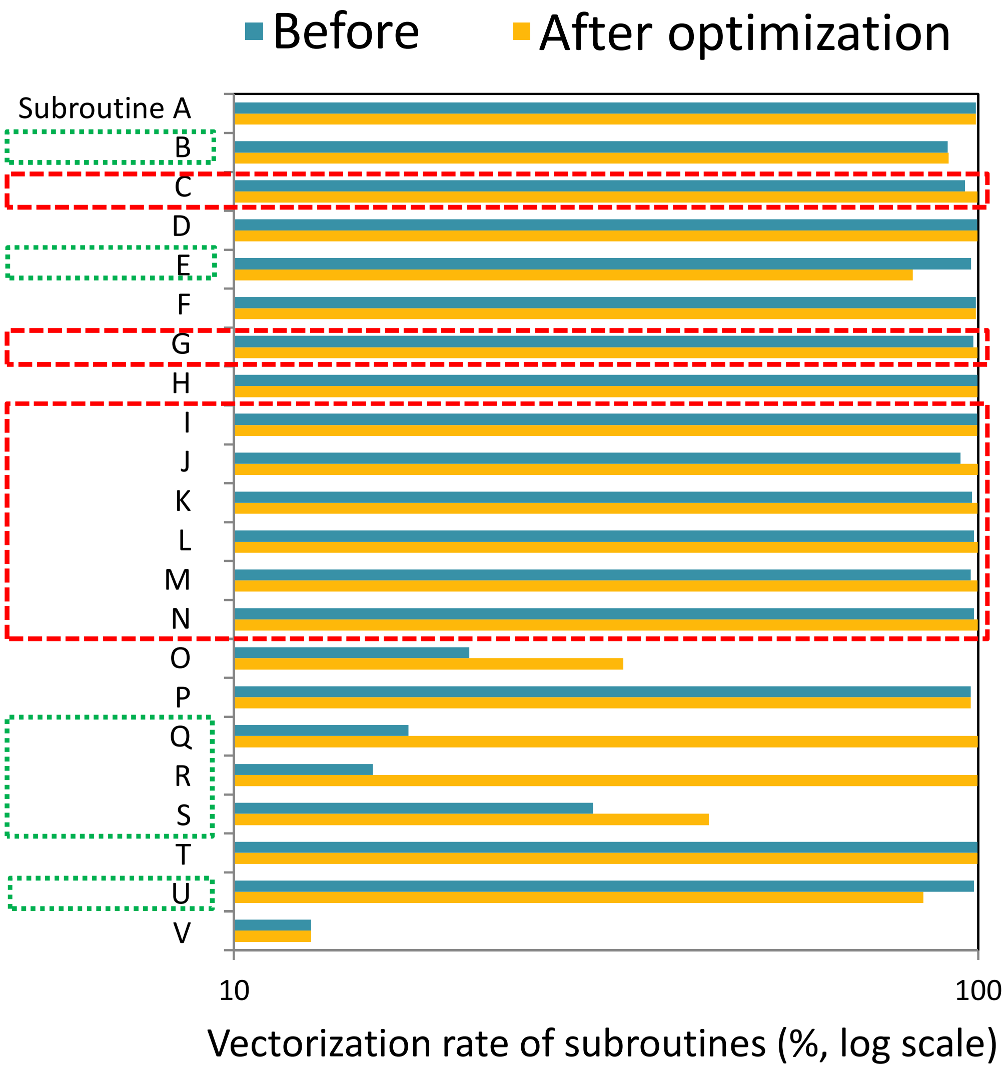


Figure. Computational time per MPI nodes（After optimization）

Vectorization rate before and after optimization



Main routines

⇒ Achieved more than 99.7% of V.R.

MPI related routines

⇒ Communication part cannot be vectorized.

- High performance is achieved by enhanced scalar performance of SX-ACE®, even though high vectorization rate (>99.9%) is not achieved due to the nature of the code.
- SX-Aurora TSUBASA® also shows the consistent performance with these results.

Application of CFD : wind load assessment

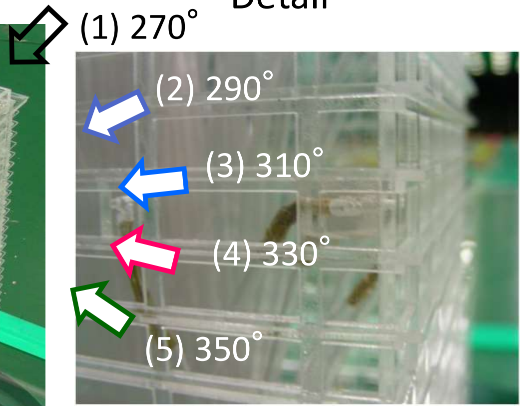
Validation target:　Experiment for wind loads acting on external materials

- Scale model with complex surface geometry　(Column, beam, slab)
- Wind direction (the angle of attack)　5 Cases ((1)〜(5))

Scale model

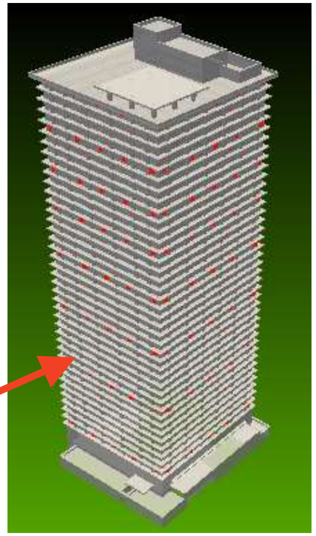
Overview

Detail

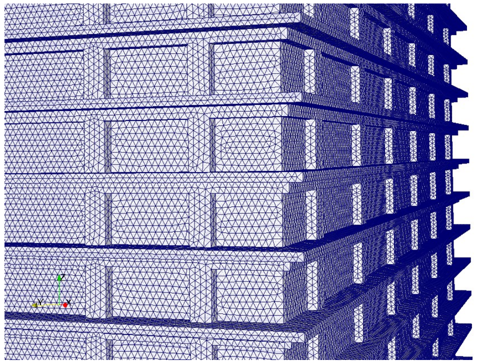


CFD model

Overview



Detail



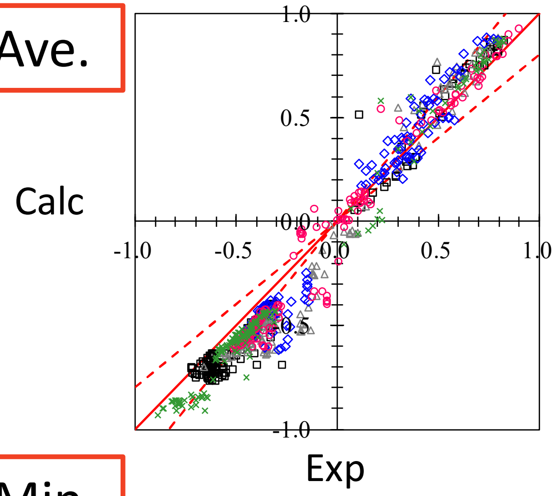
At every taps (red points in CFD overview), the experimental pressure values are obtained and compared with CFD.

Validation results (Pressure coefficients)

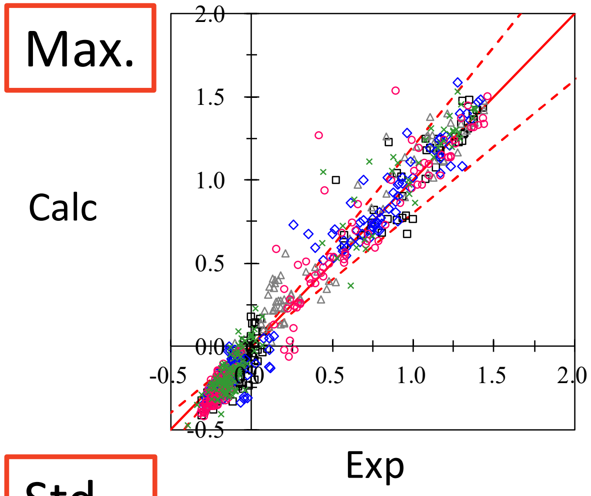
Legend
Exp : Wind tunnel
Calc : CFD(LES)
□ 270°
△ 290°
◇ 310°
○ 330°
× 350°
Red line: y=x
Red dashed
: Exp±20%

Pressure coefficient the pressure that is non-dimensioned by the velocity pressure at the height of the target building

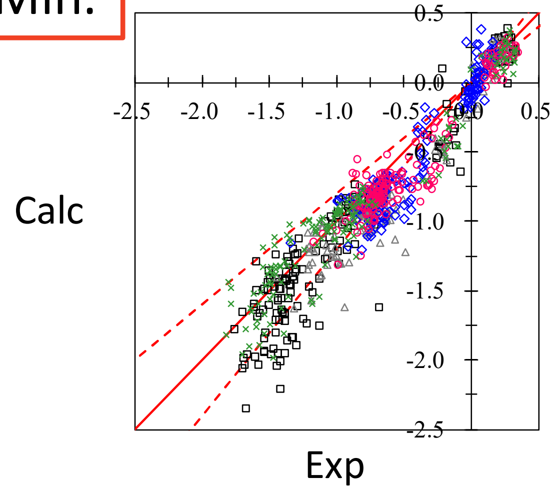
Ave.



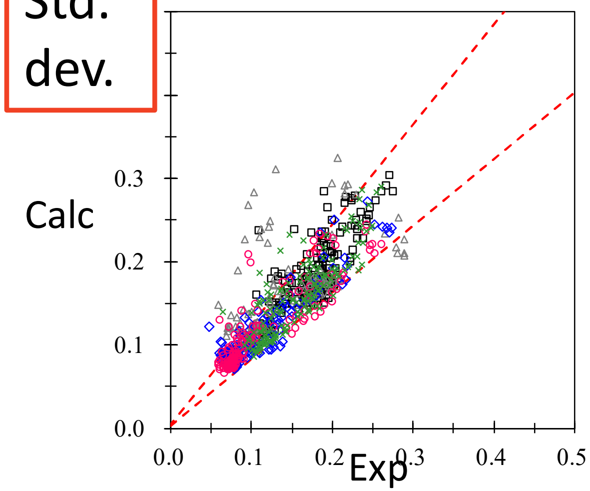
Max.

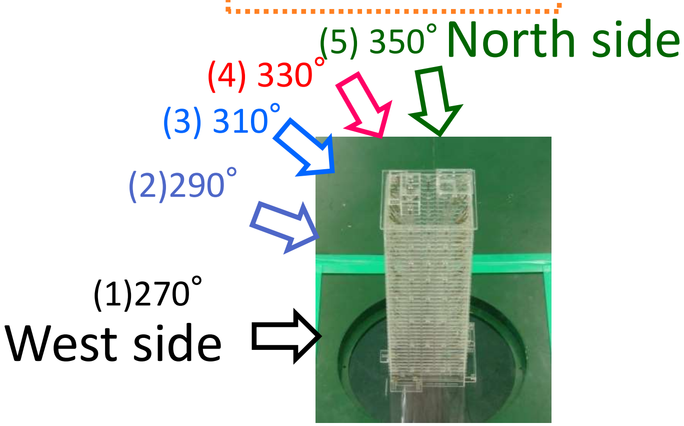


Min.

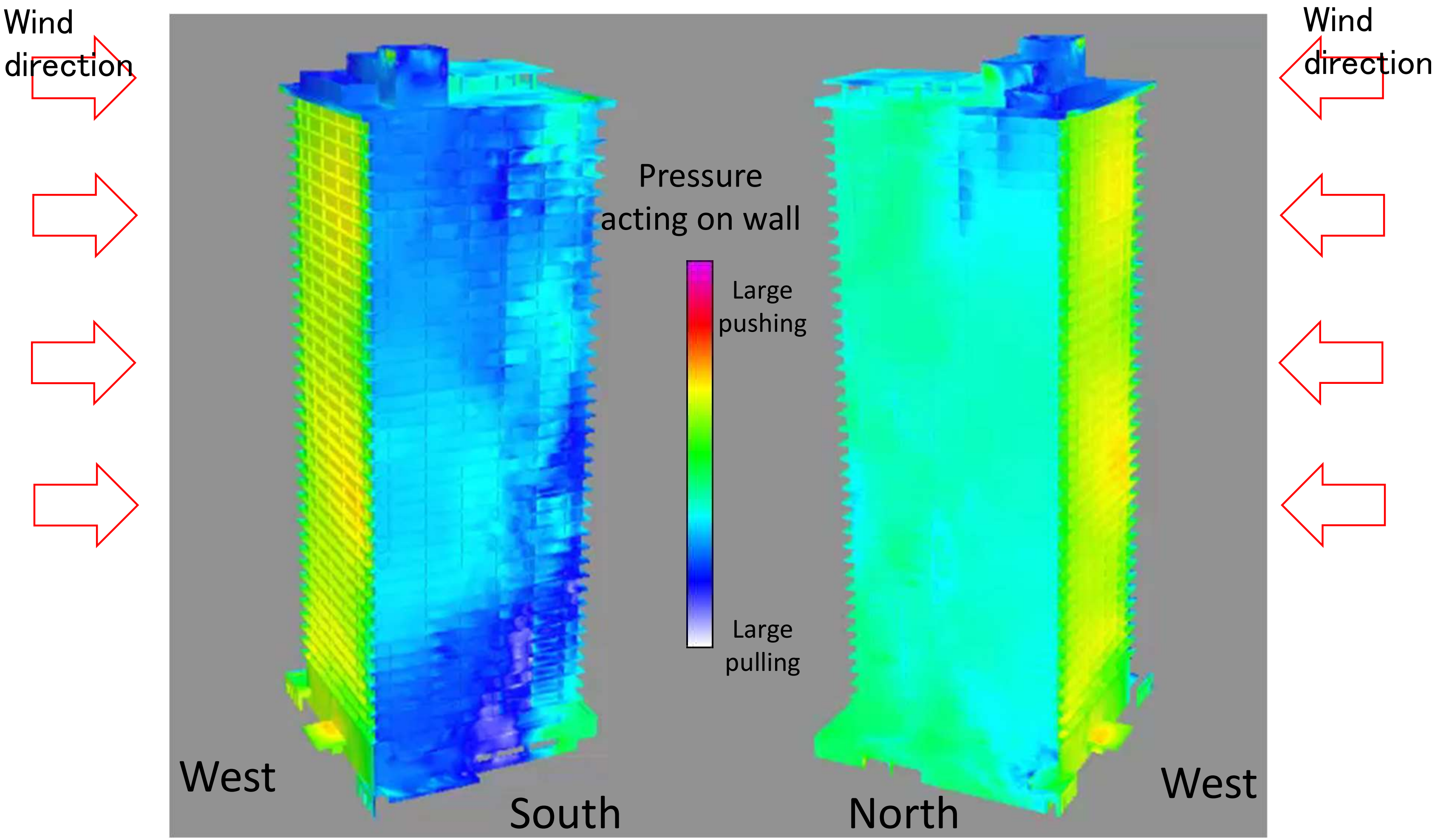


Std. dev.





Pressure distribution on wall (Case 1 : Angle of attack 270°)



Surface pressure distribution of south and north side of building at the same time.

Surface distribution of the minimum pressure coef.

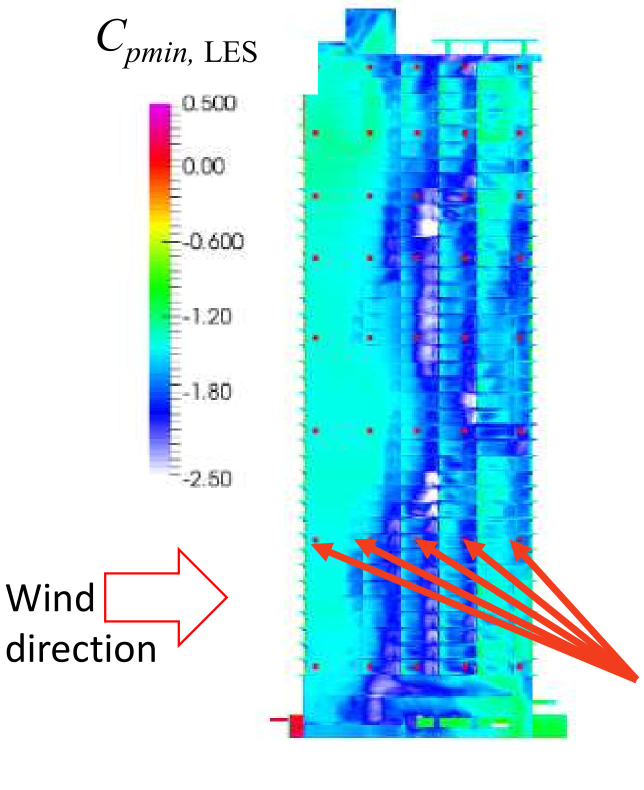


Fig. The min. pressure distribution on the south side.

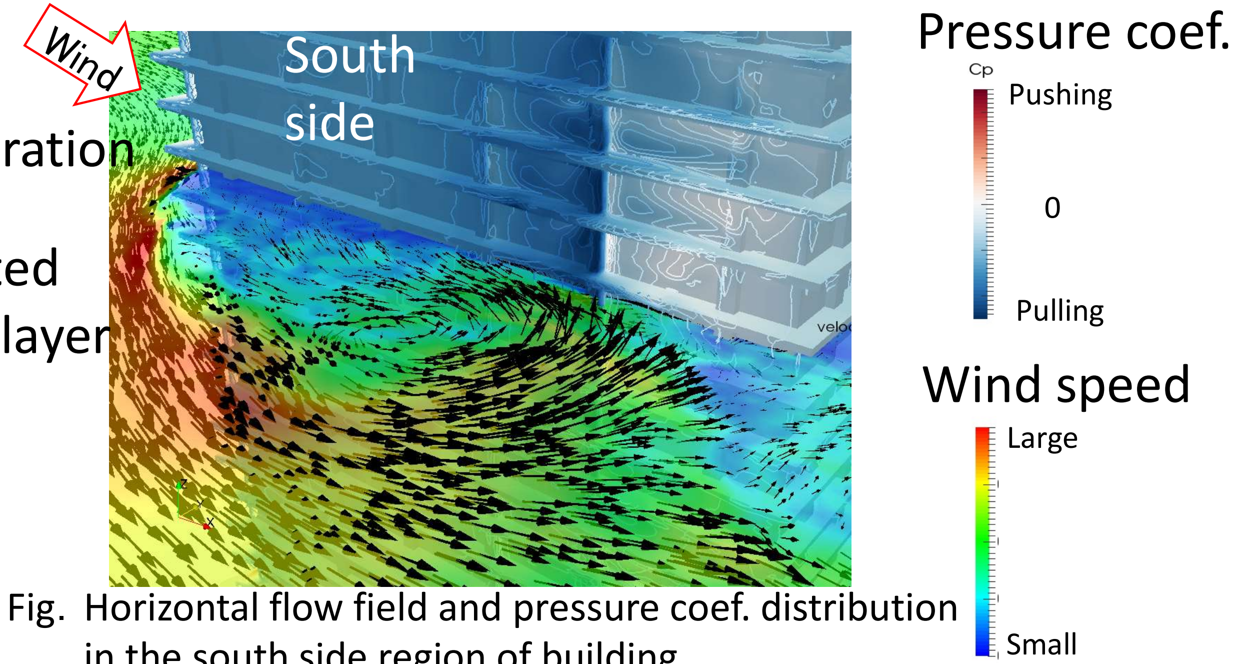
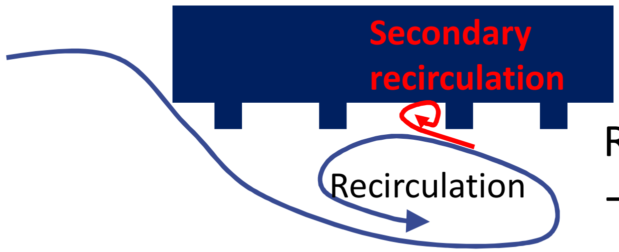


Fig. Horizontal flow field and pressure coef. distribution in the south side region of building



Recirculation + column shape
→ Secondary recirculation
→ Negative large pressure

Difficult for the experimental WT to catch such small but important flow structures.

➡ CFD technology with HCP brings new insights and knowledges to the construction industry.

The application of HPC to the offshore wind energy

Topic 2

Offshore wind energy in Japan

World Global warming, climate change

Japan → Sustainable energy “Wind”

- 2020.10 “Carbon neutrality by 2050”
- 2020.12 “Vision for offshore wind power industry” ※1

10 GW by 2030, 30～45GW by 2040 will be installed.

→ Tens of billion of dollars investment (Expected by JWPA)

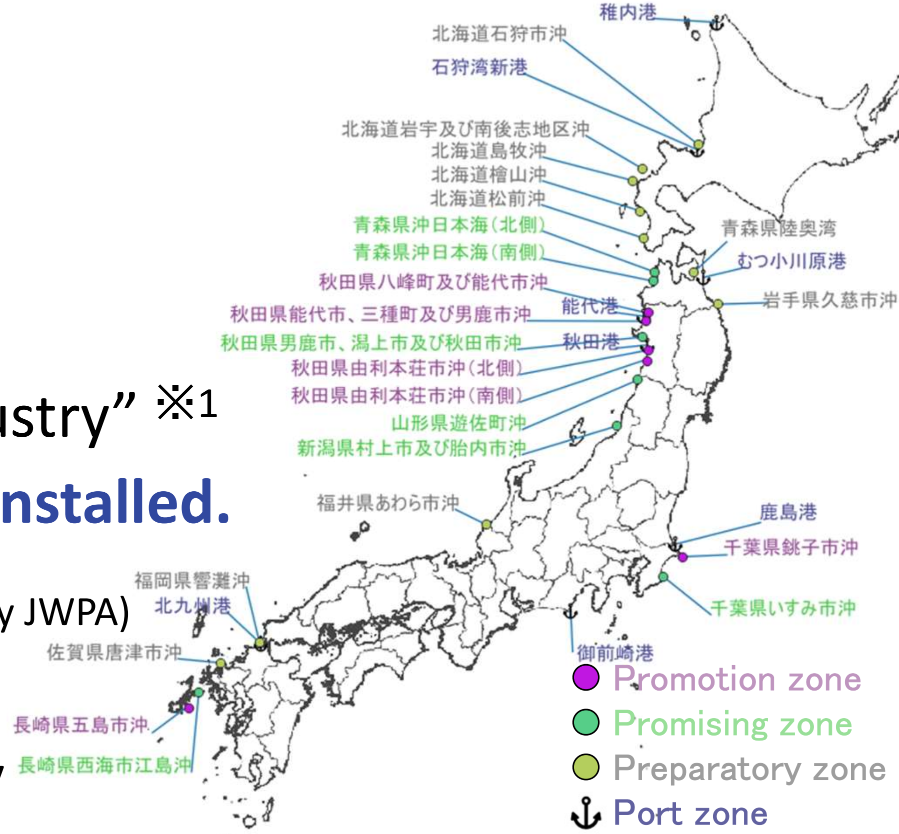


Fig. Promoting area map (status in FY 2021)
（Area info.: METI, MLIT. Background Map: GSI)

Regulatory frameworks for offshore wind energy

- 2016 Port and Harbor Act revised. “Port zone”
- 2019 Act to Promote Offshore Renewables※2 “General sea areas”

※1 Public-private council on enhancement of Industrial Competitiveness for Offshore wind power generation
※2 Act on promoting the utilization of sea area for the development of marine renewable energy power generation facilities

Wind assessment for offshore project

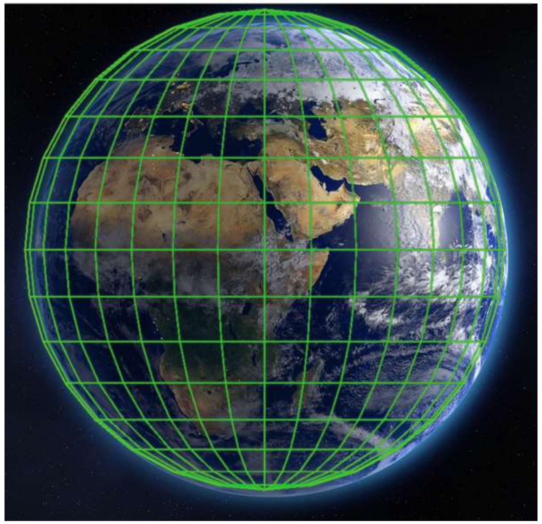
Onsite measurement in offshore: Costly, limited ⟷ Large scale projects: Vast, long term

→ **Meteorological simulation**

The same technology as the numerical weather prediction model for the weather forecast.

Benefits

- The past state of atmosphere is obtained. (spatial - temporal distr. of wind)
- No onsite measurement is required.

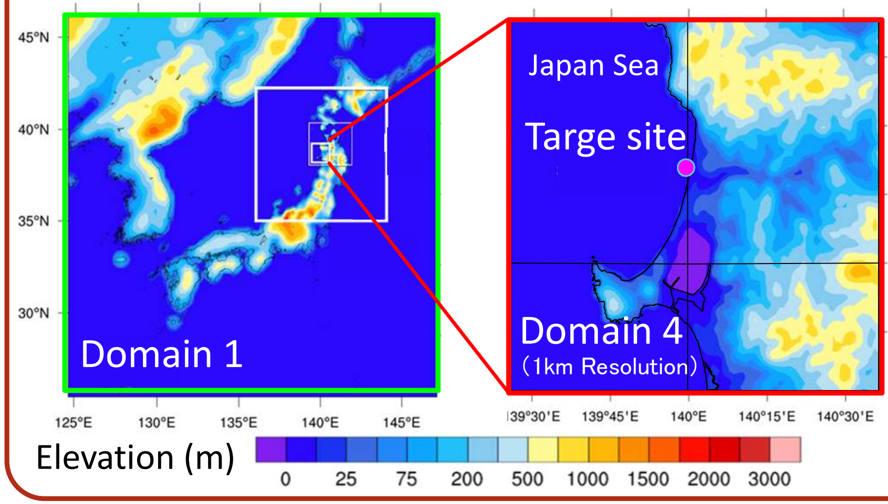


Reanalysis (global met-ocean database)
（ECMWF, NCEP ~100km resolution）

Initial/boundary conditions →

Meteorological simulation

Based on WRF※1, optimization studies of the simulation model are carried out for site by site.

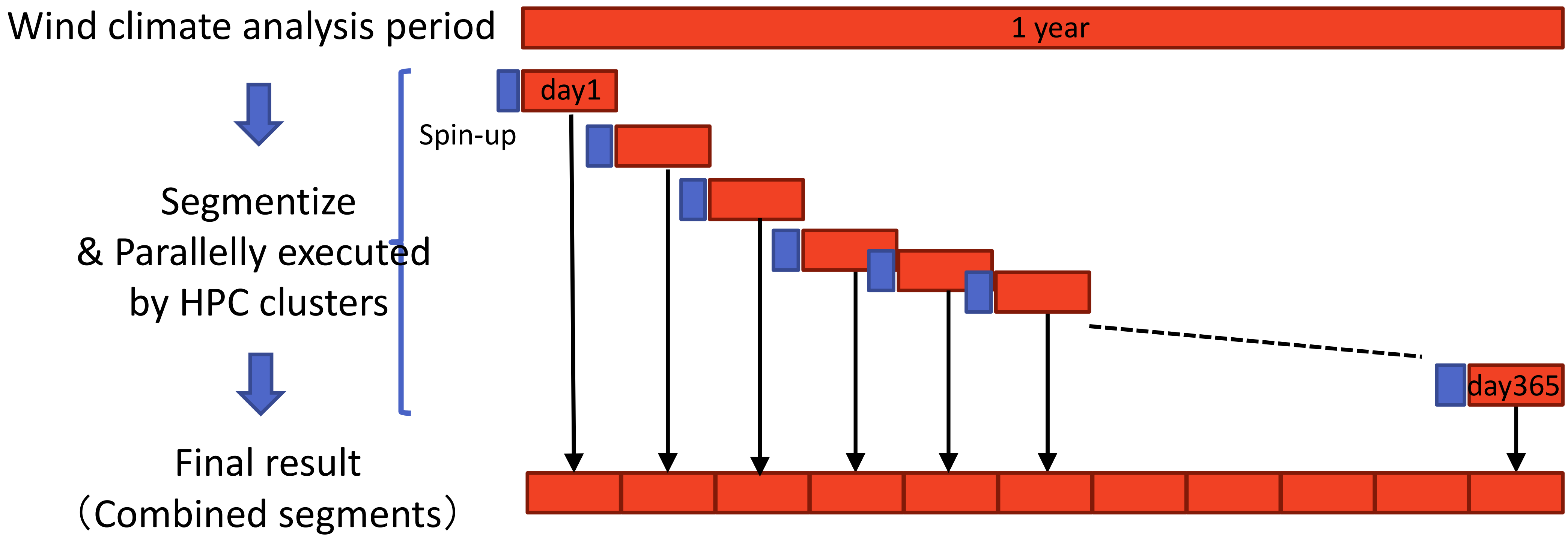


※1 Weather Research and Forecasting Model (NCAR)

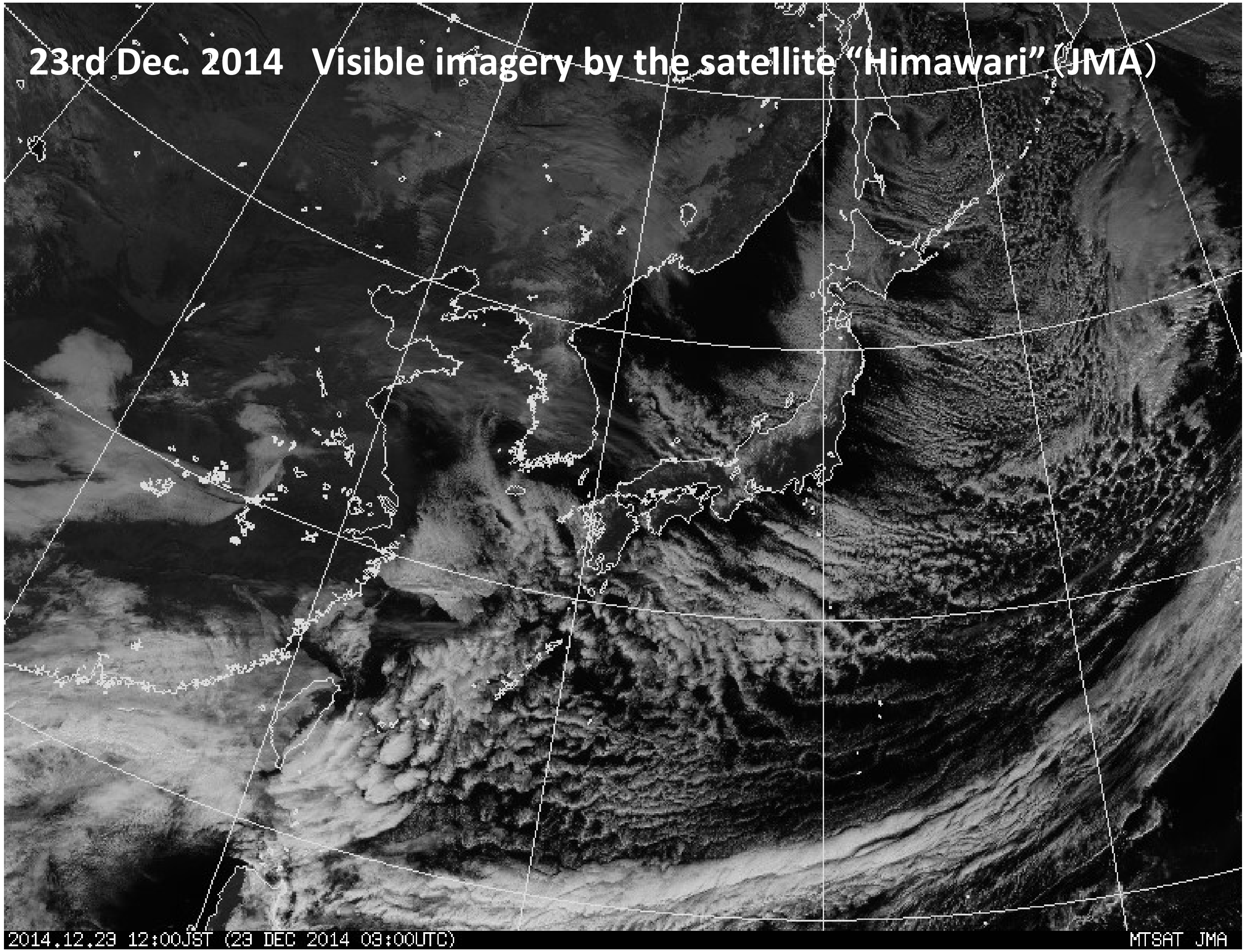
Segmentization & parallel processing for the long-term simulation

Long calculation time is needed for one-year meteorological simulation with 1km high resolution.（3 month for continuous calculation in this case.）

→ Segmentization & Parallel processing of segments reduced time to 1 week.



An example of meteorological simulation



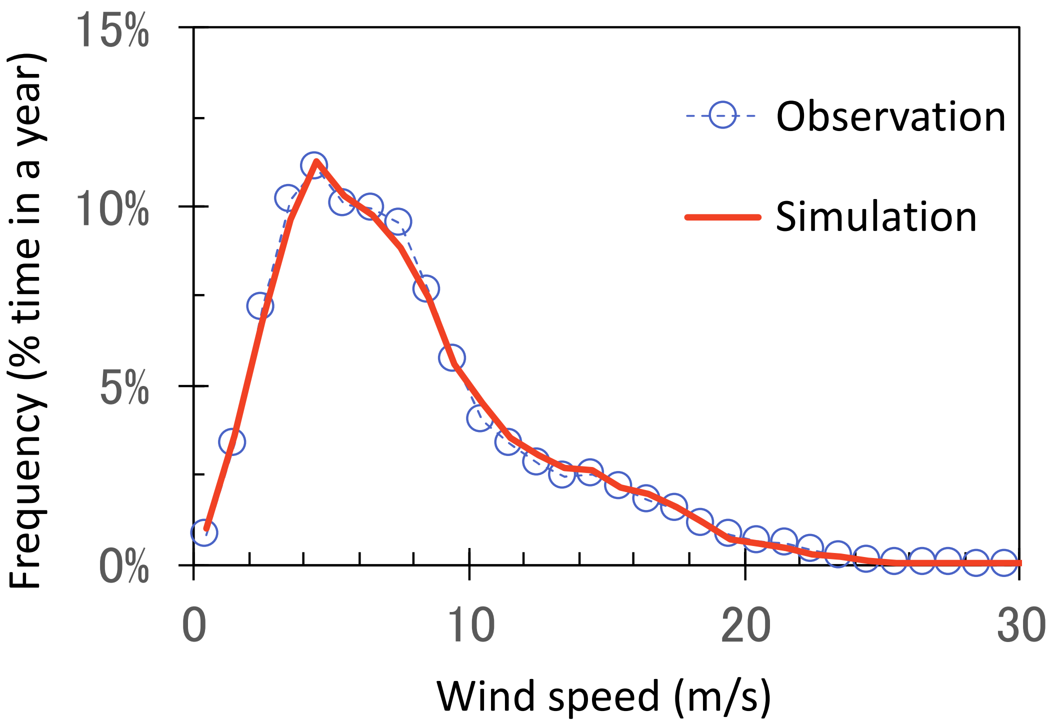
Validation

Wind climate simulated by HPC is compared with onsite observation.

High accuracy: Annual mean error less than 3%.

High speed: One-year climate is obtained in a week.

Location of met mast
（Background aerial photo: GSI）



Wind speed distribution (Height 50m)

Conclusions

The application cases utilizing HPC have been introduced to show a wide range of possibilities in construction industry, particularly focusing on wind engineering fields.

1. The development of the CFD technology to assess the wind load acting on high-rise building have been introduced. The benefits of CFD with HPC have been also presented through the validation by comparing with the conventional wind tunnel experiment.
2. In the offshore wind climate assessment, it has been shown that the long-term accurate wind climate is obtained in a short time by the combination of the segmentized meteorological simulation and the parallel computation.

Thank you !