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Joint Press Conference

Fujitsu and Yokohama National University achieve world's first real-time prediction of tornadoes associated with typhoons using supercomputer Fugaku

February 12, 2025

YOKOHAMA National University
Typhoon Research Center Vice-Director
Kazuhisa Tsuboki
Fujitsu Limited
Head of the Computing laboratory
Kohta Nakashima

Typhoon Science and Technology Research Center (TRC), Yokohama National University

By sharing each other's expertise, we enhance our understanding of typhoons and work towards realizing our missions.

Total of 83 members from 11 universities, 7 research Institutes, 6 companies, 2 overseas organizations

Director：Prof. Hironori Fudeyasu

Vice Directors： Prof. Kazuhisa Tsuboki・Prof Masaki Satoh, Prof. Nobuhito Mori, As. Prof. Taiga Mitsuyuki

Support team

Reader: Takafumi Yamamuro

Typhoon Observation Research Lab

Leader：Nagoya U./YNU Porf. Kazuhisa Tsuboki

Meteorology

●Nagoya U
●U Ryukyus
●JAMSTEC
●Hokkaido U
●JAXA
●NIED
●OIST
★KHI

Typhoon Prediction Research Lab

Leader：U. Tokyo /YNU Prof. Masaki Satoh

Meteorology

○YNU
●U Tokyo
●Kyoto U
●Tohoku U
●MRI
●U Ryukyus
●JAMSTEC
●Keio U
●CMA
●UCAR

Typhoon Power Generation System Development Lab

Leader：YNU Assoc. Prof. Taiga Mitsuyuki

Naval architecture
Electronics engineering

○YNU
●JAMSTEC
●NEDO
●Hokkaido U

Social Implementation Promotion Lab

Leader：YNU Prof. Seiji Manabe

Economics
Law
Psychology

○YNU
★Deloitte Tohmatsu
★TMRI
★KHI

Regional disaster prevention Lab

Leader：Kyoto U./YNU Prof. Nobuhito Mori

Education

●Kyoto U
○YNU
●Chiba U
●MPAT
●Ochanomizu U
★Aioi Nissay Dowa
★TMRI
★MS&AD

Typhoon data science Lab.

Leader：YNU Assoc. Prof. Ryuji Yoshida

Statistics

○YNU
●JAMSTEC
●NII
★Fujitsu Lab

International Advisor

Prof. Kerry A. Emanuel(MIT)
Prof. Yuqing Wang(UH)
Prof. Chun-Chieh Wu(NTU)
Prof. Roger K. Smith (LMU)
Prof. Johnny Chan (City-U; AP-TCRC)
Prof. David Nolan (UM)

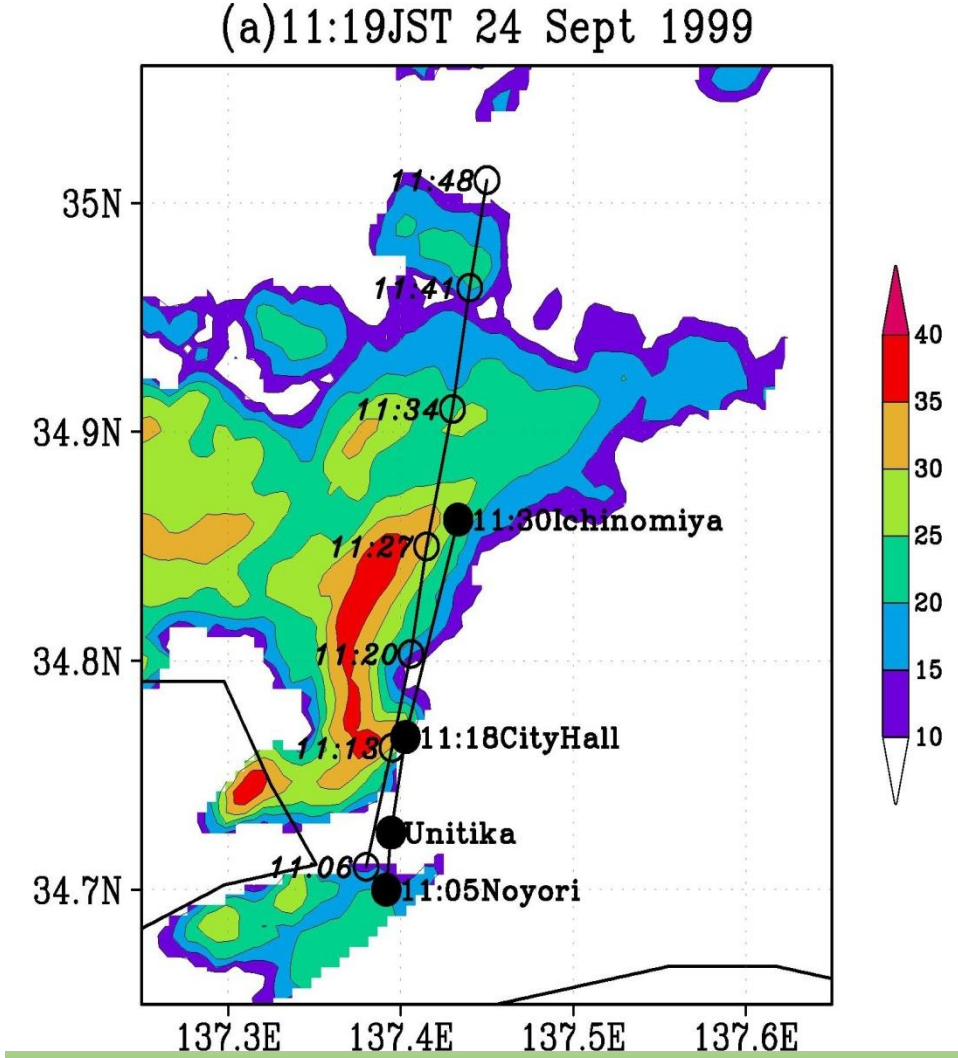
Definition of Tornadoes (Tatsumaki in Japanese)

- Definition: “A tornado is a violent vortex around a vertical axis associated with convective clouds such as cumulonimbus clouds, often accompanied by funnel or columnar clouds.” (Japan Meteorological Agency, 1988)
- Tornadoes can be divided into a supercell-type and a non-supercell type. Generally, the strong tornadoes are usually the supercell-type.
- A tornado is “a vortex in which the balance between centrifugal and barotropic forces. The cyclostrophic balance is established with extremely high accuracy.”
- The vorticity is about 0.1 to 1/s. (Supercell (mesocyclone) is about 0.01/s, and extratropical cyclone is about 0.00001/s.)

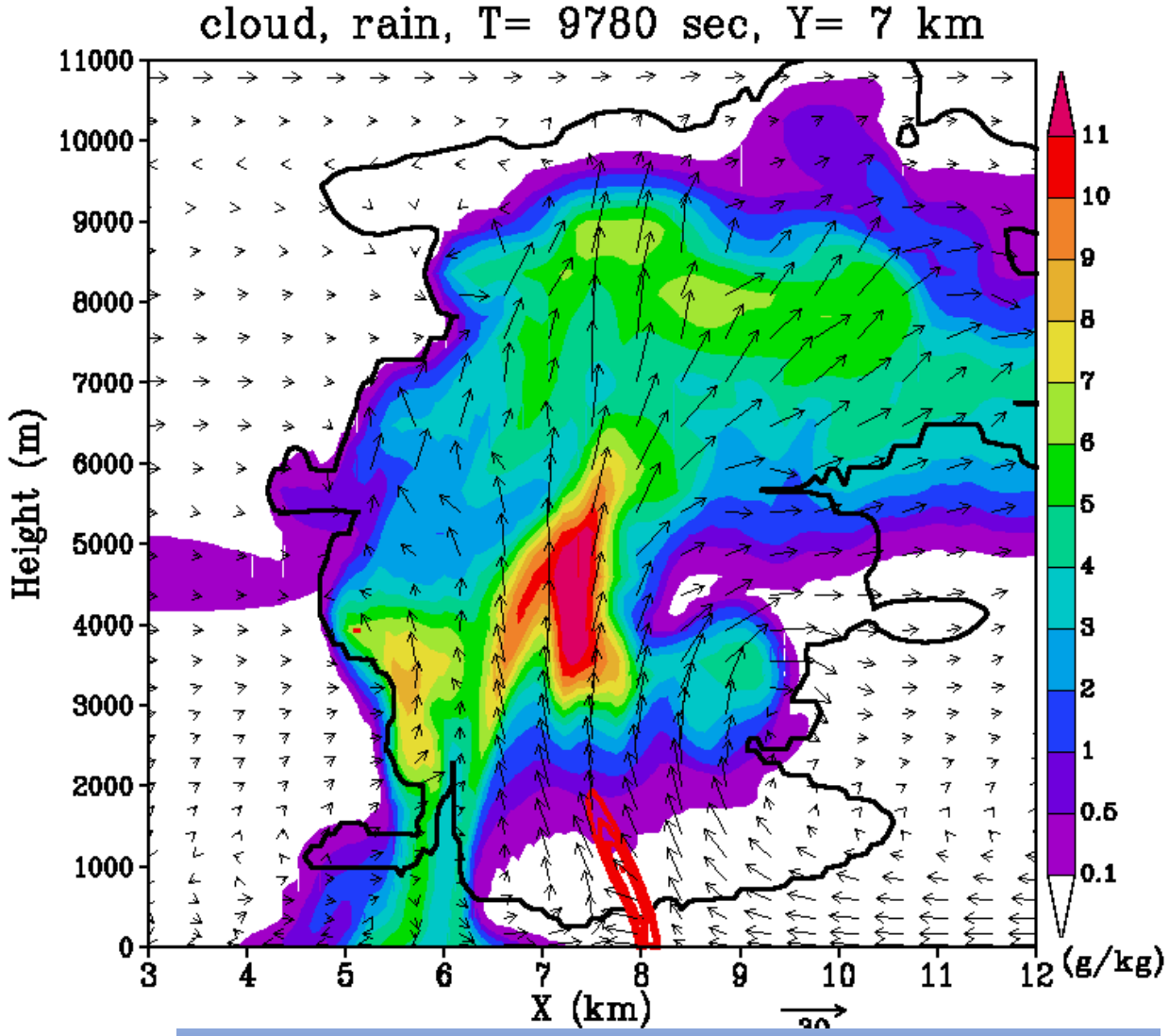
Difficulty in predicting tornadoes

- Tornadoes are so small that they cannot be observed directly, but their destructive power is the strongest of all atmospheric disturbances. Moreover, tornadoes form and develop very rapidly.
- Tornadoes occur anywhere in Japan and its surrounding areas, in any season. Per unit area, the number of tornadoes in Japan is about the same as the number of tornadoes in the North America.
- They are also difficult to simulate, and no numerical forecast models are used to predict them.

A supercell-type tornado



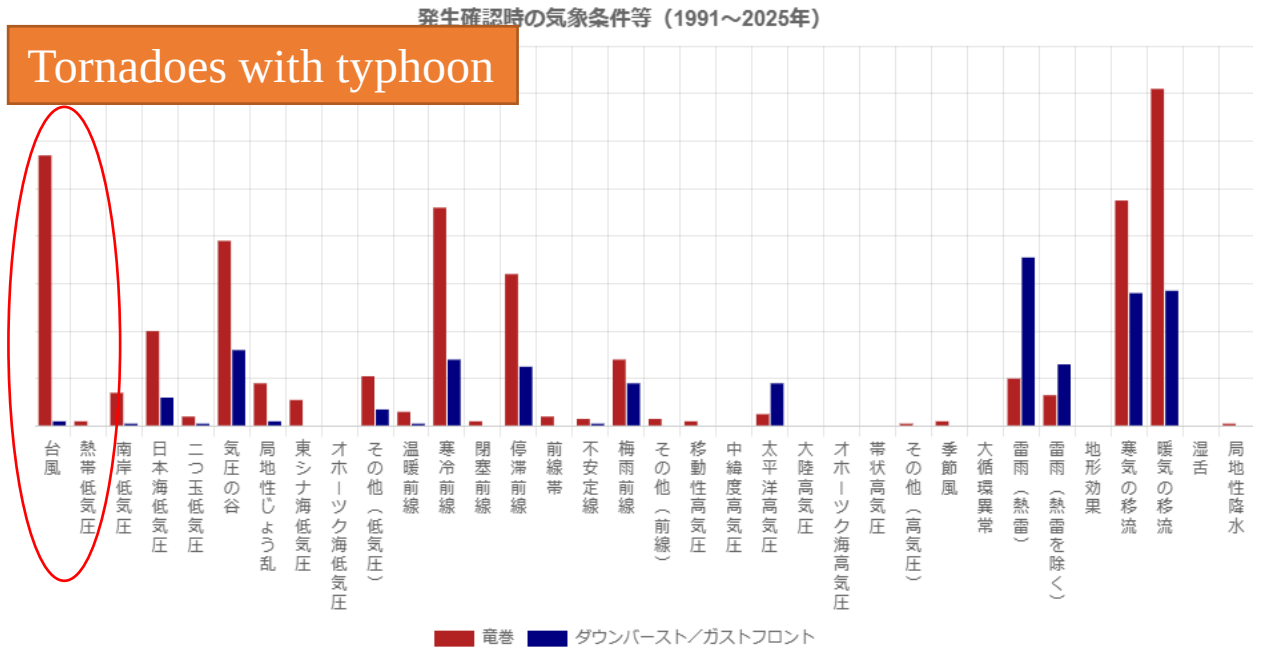
Horizontal display of radar echo of a supercell. Open circles are position of mesocyclone and the closed circles are that of the tornado.

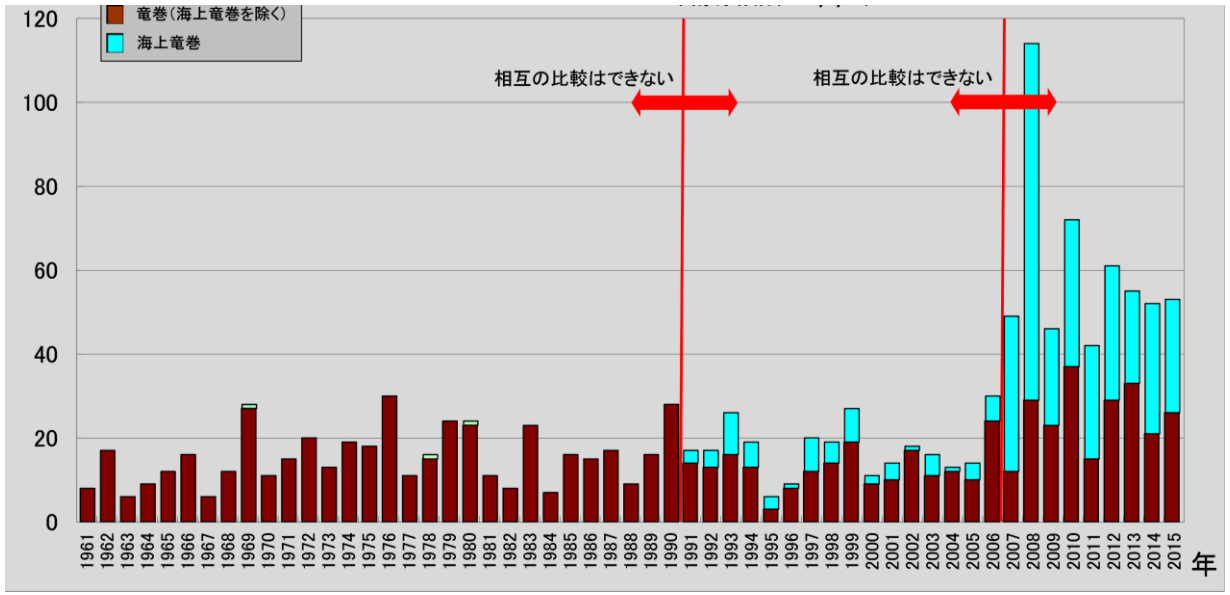


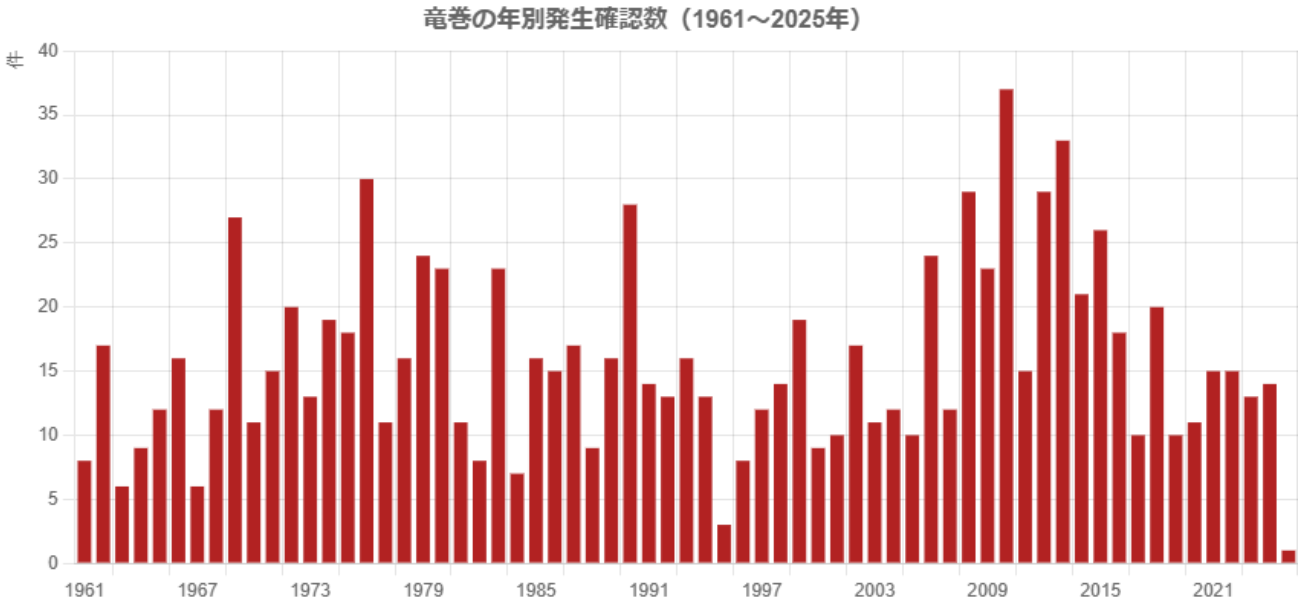
Vertical cross section of a simulated supercell. Color levels are precipitation. Red contours are vorticity (tornado).

Distribution, number of occurrences, and weather conditions of tornadoes (gusts) in Japan

Tornadoes with typhoon







Source: Japan Meteorological Agency website

Accuracy of Tornado Warning Information

竜巻注意情報の精度について

平成20年3月26日から令和6年12月31日までの精度の推移（令和7年1月15日更新）

	平成22年	平成23年	平成24年	平成25年	平成26年	平成27年	平成28年	平成29年	平成30年	令和元年	令和2年	令和3年	令和4年	令和5年	令和6年※
適中率 (括弧内)は 最大瞬間風速20m/s以上の 事例を含めた適中率	5% (26%)	1% (18%)	3% (25%)	4% (24%)	2% (22%)	4% (24%)	4% (25%)	2% (18%)	3% (25%)	4% (29%)	4% (32%)	4% (27%)	2% (24%)	6% (22%)	2% (16%
捕捉率 [括弧内]はJEF1以上の捕捉率	34% [67%]	21% [20%]	32% [40%]	42% [38%]	27% [33%]	35% [78%]	39% [50%]	41% [36%]	48% [42%]	37% [56%]	38% [22%]	44% [57%]	17% [13%]	55% [53%]	47% [54%
発表数	490	589	597	606	604	402	372	909	648	331	349	427	319	591	561
突風回数 [括弧内]はJEF1以上の回数	67 [6]	39 [5]	50 [10]	59 [21]	37 [6]	48 [9]	41 [14]	46 [11]	48 [12]	41 [9]	40 [9]	43 [7]	36 [8]	62 [17]	30 [13]

Source: Japan Meteorological Agency website

Expected Methods as Tornado Prediction

➢Currently, tornadoes can hardly be predicted or detected by observation. Since tornadoes are caused by cumulonimbus clouds, it is necessary to understand the characteristics of the parent cumulonimbus cloud.

＝＞Understanding the parent clouds of tornadoes is important.

➢Doppler radar observation of mesocyclones in supercell is promising. However, not all tornadoes are caused by supercells. There are unknown cumulonimbus clouds. Also, with this method, prediction is limited to about 10 minutes in advance.

➢Simulation of cumulonimbus clouds using a cloud-resolving model. It can predict the potential for tornadoes to occur several hours in advance.
=> Cloud-resolving models are expected to be used in large-scale super-computers such as Fugaku.

Numerical models in meteorology

Classification according to objectives

- GCM (General Circulation Mode), global model
- Climate model
- Regional Model (Mesoscale model)
- Regional climate model
- Cloud resolving model
- Cloud model

Classification according to basic equations

- According to vertical momentum equation
  - hydrostatic model
  - non-hydrostatic model
- According to continuity equation
  - Bousinesqu model
  - anelastic model
  - elastic model

- Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) (Grell et al. 1994)
- Weather Research and Forecasting (WRF) (Skamarock et al. 2008)
- Japan Meteorological Agency Non-Hydrostatic Model (JMA-NHM) (Saito et al. 2006, 2007)
- GRAPE-Mesoscale Atmospheric Regional Model for South China with 3 km (MARS3KM) (Zhang et al. 2016)
- Cloud Resolving Storm Simulator (CReSS) (Tsuboki and Sakakibara 2002)
- France

CReSS (Cloud Resolving Storm Simulator): High-resolution numerical simulation models

References : *Tsuboki and Sakakibara, 2002; Tsuboki, 2023*

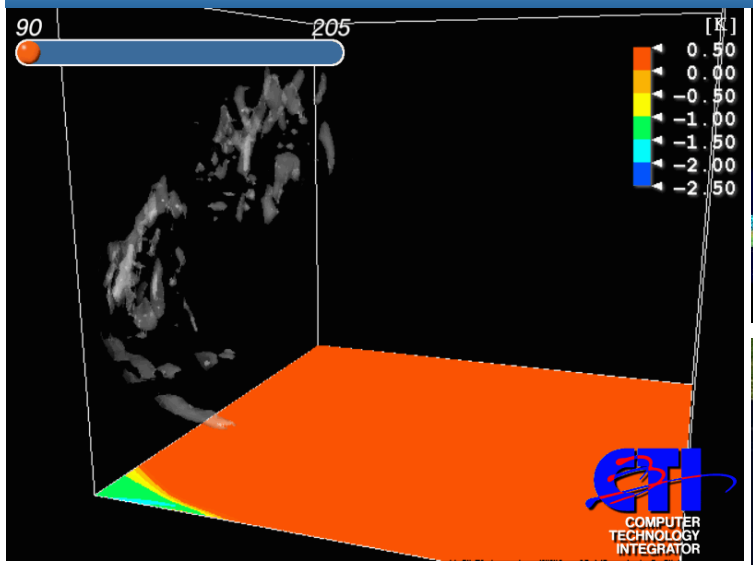
Features

1. A high-resolution weather simulator based on a cloud-resolving model, covering scales **from the cloud scale (50m–2,000m) to the mesoscale (2km–2,000km)**
2. The model can accurately simulate the **formation and development of supercell thunderstorms that produce tornadoes** at high resolution
   - The computational cost of the complex physical equations is a challenge
3. Scalable to run on various computing platforms, from laptops to supercomputers

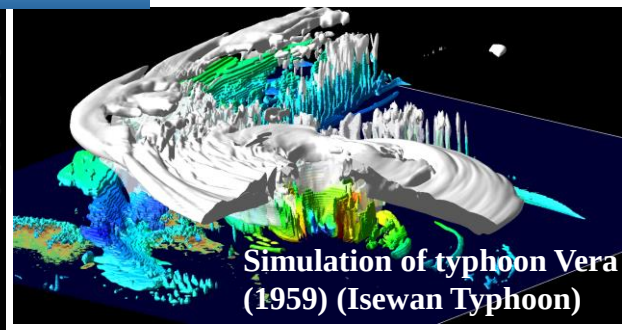
Basic equations in CReSS

- Equations of motion (NS equations + earth rotation)
- First law of thermodynamics (conservation of energy)
- Atmospheric pressure equation
- Water vapor conservation law
- Time evolution equation of turbulence
- Time evolution equation of mixing ratio of water substances (cloud, rain, snow)
- Time evolution equation of number concentration of water substances

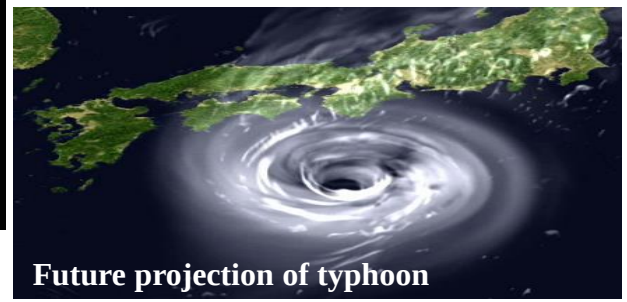
Simulation results using CReSS



Tornado experiment under idealized environment

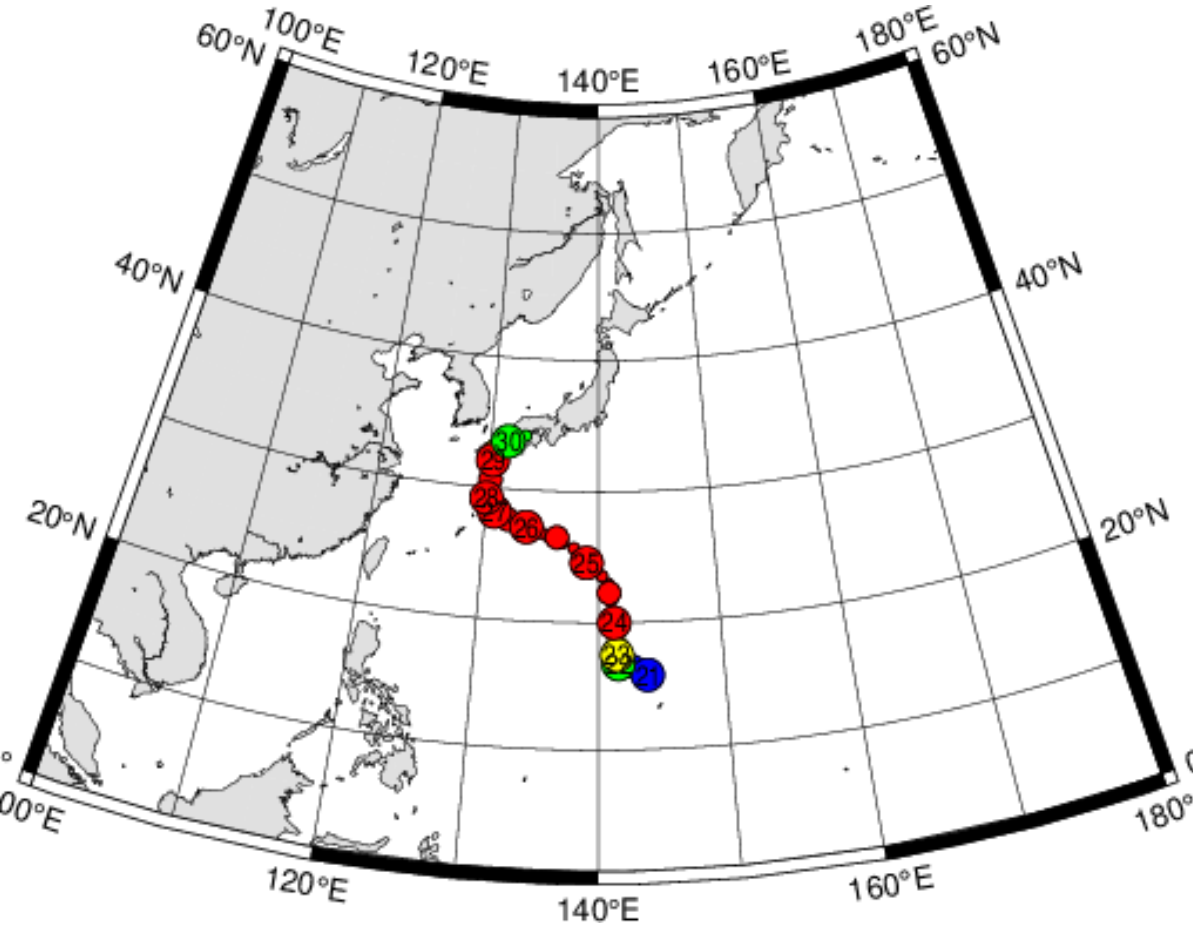


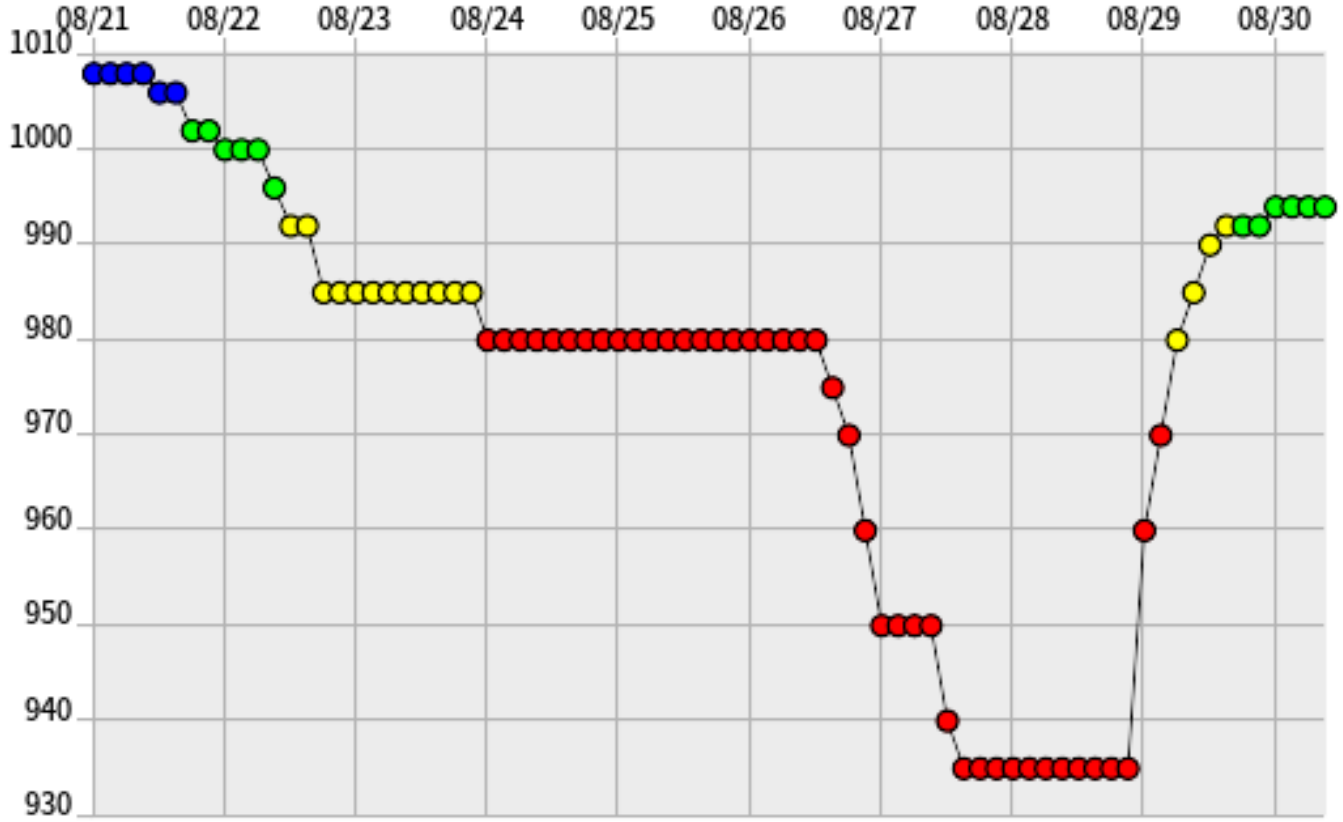
Simulation of typhoon Vera (1959) (Isewan Typhoon)



Future projection of typhoon

Typhoon Shanshan (2024)





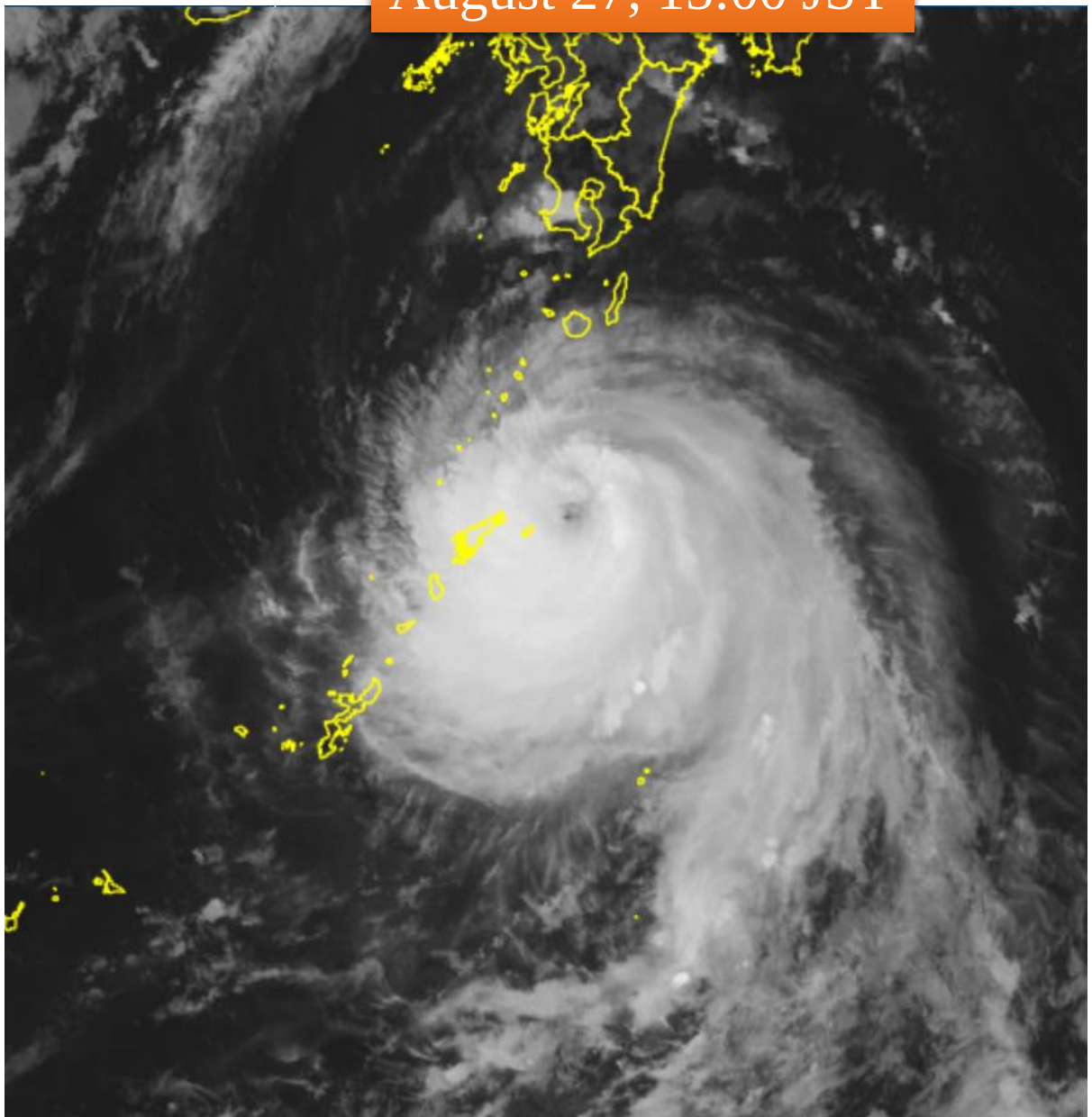
Source: Digital Typhoon

Typhoon Shanshan (2024), which originated in the Mariana Islands on August 22, moved slowly near Japan and approached the Amami region on August 27 with extremely strong force. It then shifted its course northward and approached southern Kyushu with extremely strong category, making landfall near Satsumasendai City, Kagoshima Prefecture, at around 08:00 on August 29 with strong category.
Because the atmospheric conditions were extremely unstable from western to eastern Japan, some areas were affected by tornadoes associated with cumulonimbus clouds. In Miyazaki Prefecture, several cities and towns were hit by tornadoes on the 28th and 29th.

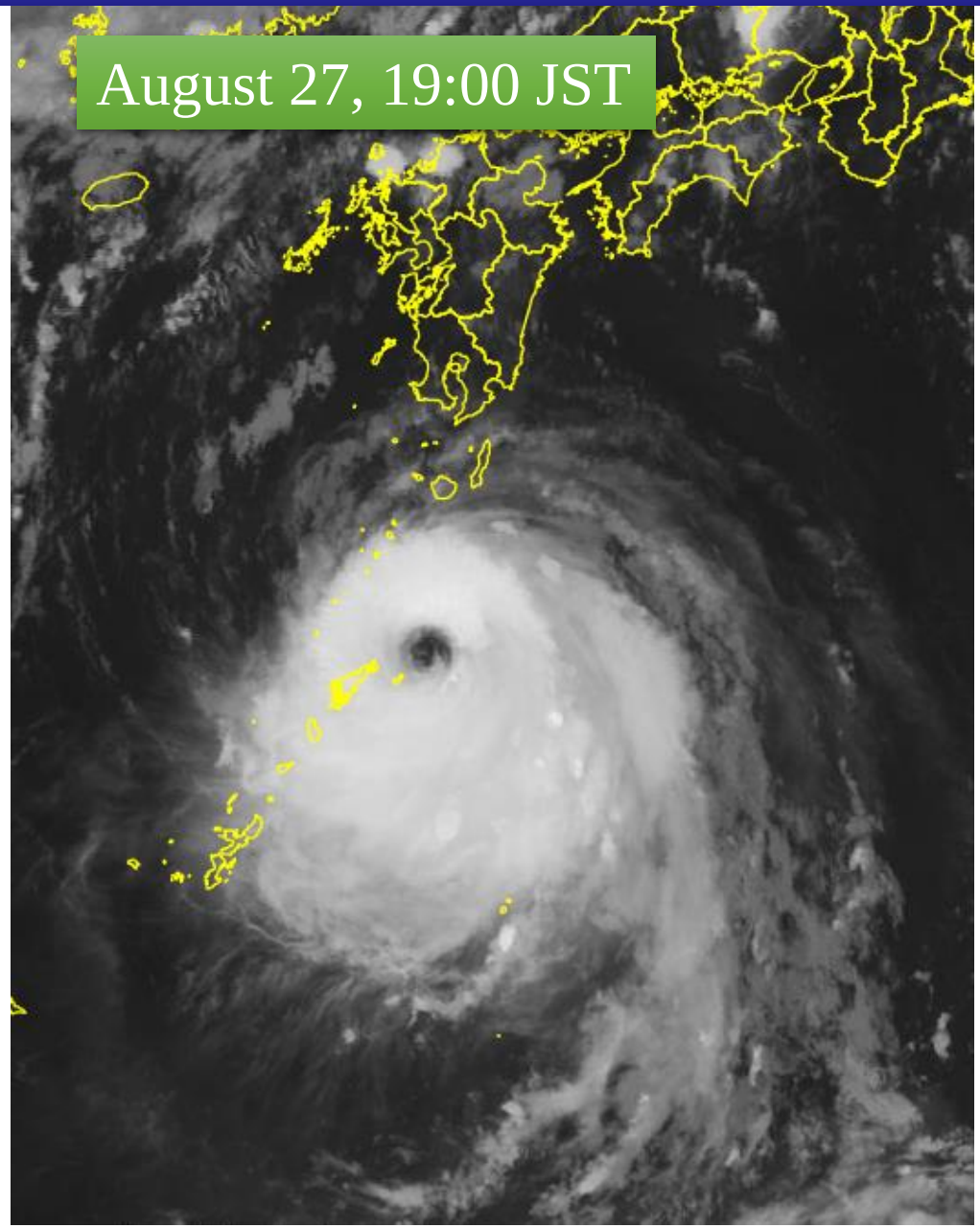
Source: Japan Meteorological Agency website

Himawari Satellite Image (Infrared Image) of Typhoon Shanshan (2024)

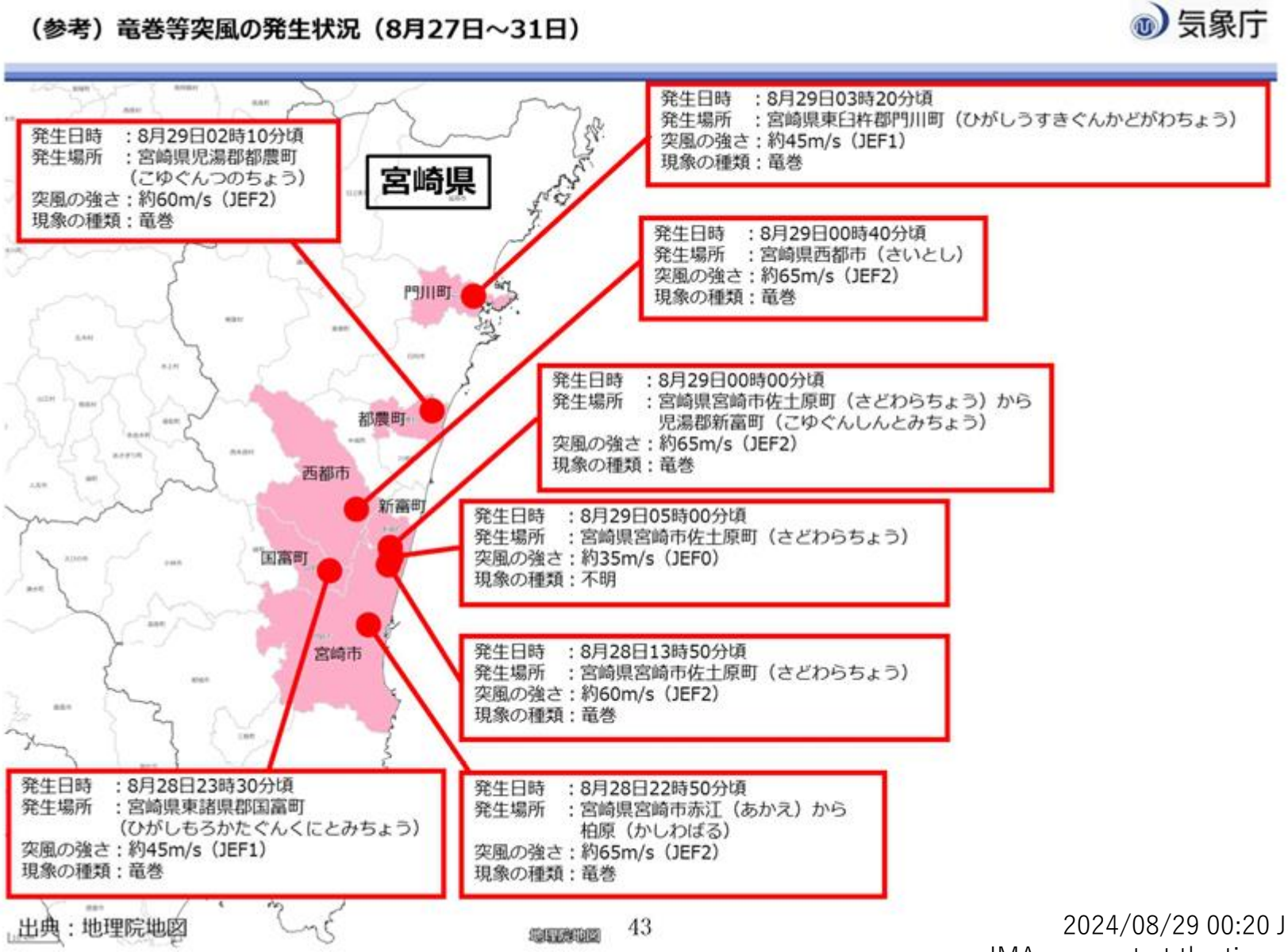
August 27, 15:00 JST



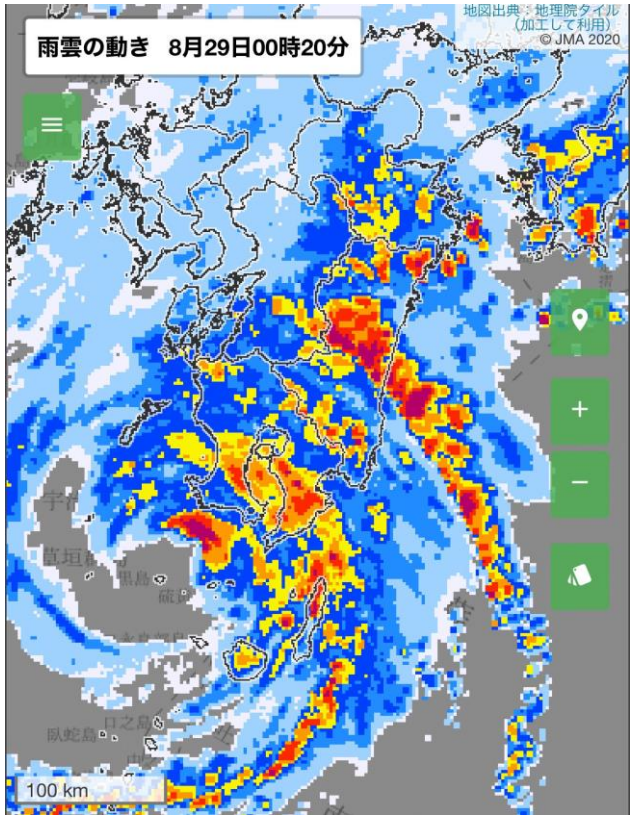
August 27, 19:00 JST



Gusty winds associated with Typhoon Shanshan (2024)



8 wind gusts in Miyazaki prefecture, including 5 JEF2 (approx. 60-65 m/s) tornadoes. Human and housing damage (as of September 9, 2024, according to Miyazaki Prefecture) Injuries: 39 (including 1 seriously injured) Houses: Half destroyed: 23 houses Partially damaged: 1149 houses



2024/08/29 00:20 JST
JMA nowcast at the time of the gust
(https://www.jma.go.jp/bosai/nowc/)

Source: Japan Meteorological Agency website

Issues and Future Directions for Tornado Research

- Using the cloud-resolving model, tornadoes themselves, along with typhoons, can now be simulated using a common grid systems.
- The use of Fugaku makes it possible to perform high-resolution simulations in large computational domains at high speed. It is possible to predict tornadoes in real time with sufficient lead time.
- However, there is currently an error in time and location, which should be interpreted as an indication that we are now able to predict tornado outbreak potential. In the future, the extent to which time and location can be predicted with high accuracy should be examined, and what is needed to improve the accuracy.
- There are typhoons that produce tornadoes and those that do not. The issue is to be able to distinguish between these typhoons and accurately forecast tornadoes associated with typhoons.
- This experiment uses 5% of Fugaku's resources. This means that ensemble forecasts with 20 members are possible at the same time. It is hoped that this will be developed into an ensemble forecast for tornadoes.
- It is an important issue to make it possible to forecast tornadoes associated with parent systems other than typhoons as well.

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Joint Press Conference

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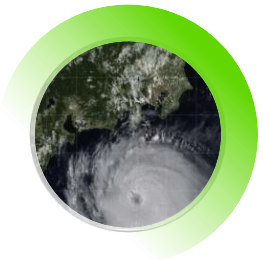
Head of the Computing laboratory
Kohta Nakashima

Target Innovation Driven by High-performance Computing

To reduce weather disaster damage, Fujitsu has set up a Small Research Lab with YNU's top typhoon researchers to drive innovation

Tornado forecasts with typhoons



Beyond the limits of innovation

Weather simulation can **simultaneously reproduce both the entire typhoon and tornadoes**

Target innovation and goals

Highly accurate tornado forecasting, previously mostly unpredictable, will reduce damage significantly

Discovery of zero-emission materials

A technology **to elucidate reaction energies** results in the discovery of a groundbreaking new material

Personalized medicine

To develop **a whole-genome-based pathogenicity prediction technology** for personalized medicine

Fujitsu - Yokohama National University Typhoon Science and Technology Research Center Collaborative Research Laboratory

Period: From November 2022

Key technology: Computing, AI

Technology FUJITSU

Sophistication・Acceleration

of typhoon dynamics and forecasting

TRC Typhoon Science and Technology Research Center **Research**

Large-scale parallelization of CReSS: Challenge

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Objective: Real-time prediction of typhoon-associated tornadoes using CReSS

- **Simulate entire typhoon at tornado-resolving resolution**
  600 km square discretized at 80 m resolution, requiring 3 billion data points to be calculated
- **The calculation and data store of 3 billion points must be fast**
  Utilize Fugaku for real-time processing of vast computations and data

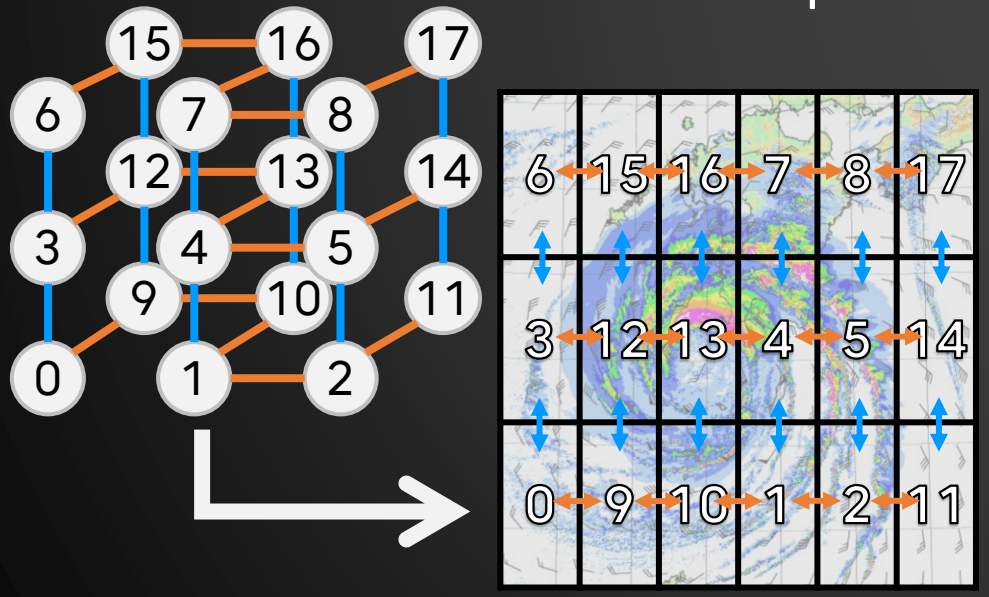
Large-scale parallel processing technology is essential to fully utilize the vast computational resources of Fugaku

Large-scale parallelization of CReSS: Technology

Communication Optimization:

Keeping high parallel efficiency

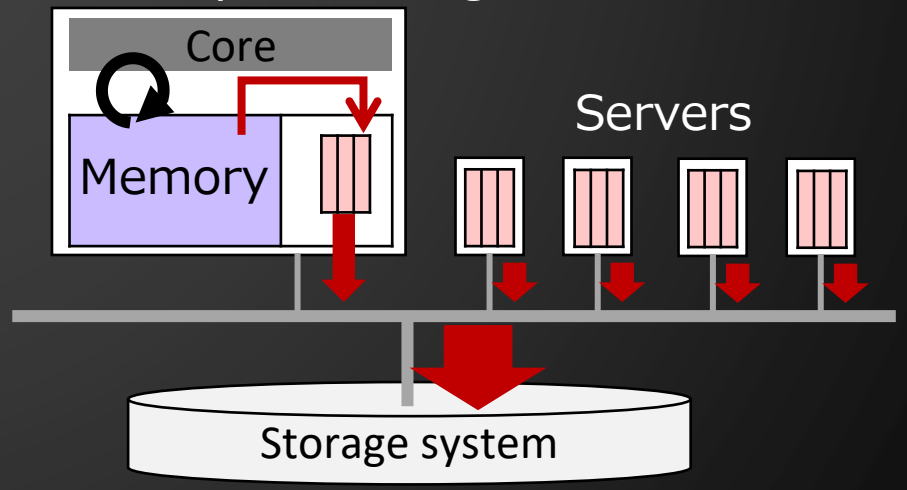
- Optimal process mapping for 6-D mesh/torus structure
- Removed redundant comm. paths



File Access Optimization:

Reduction of data output overhead

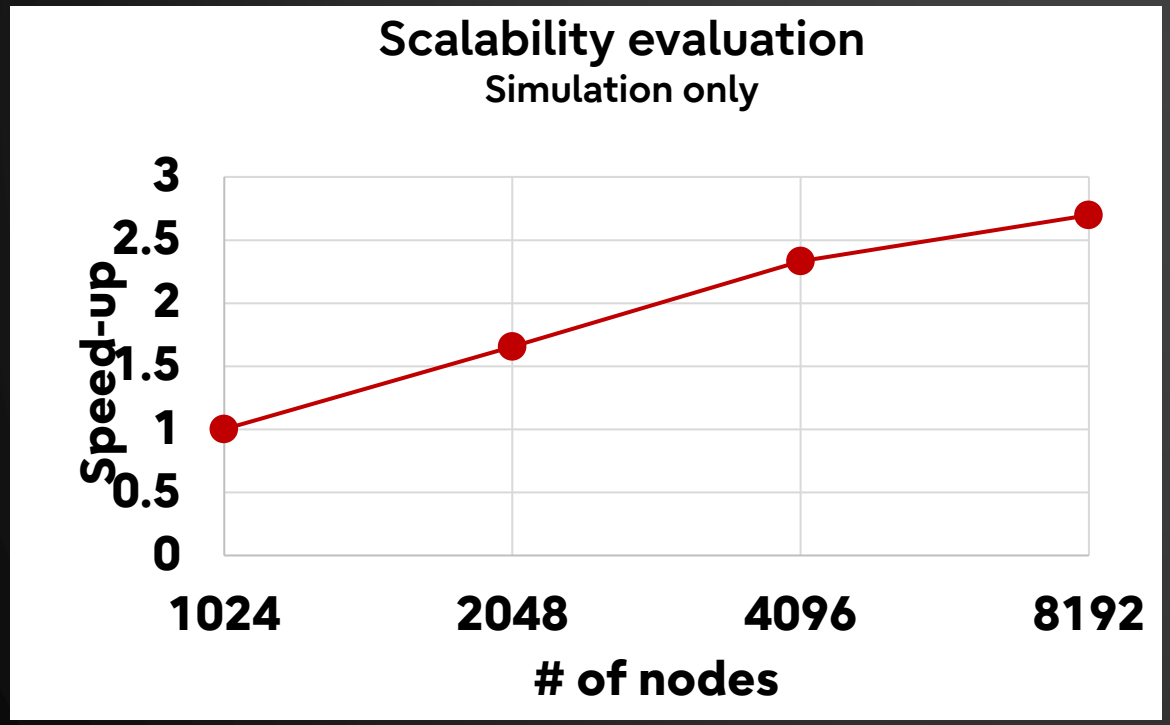
- Reduce output costs through in-memory data merging
- Overlap between write operation and simulation processing

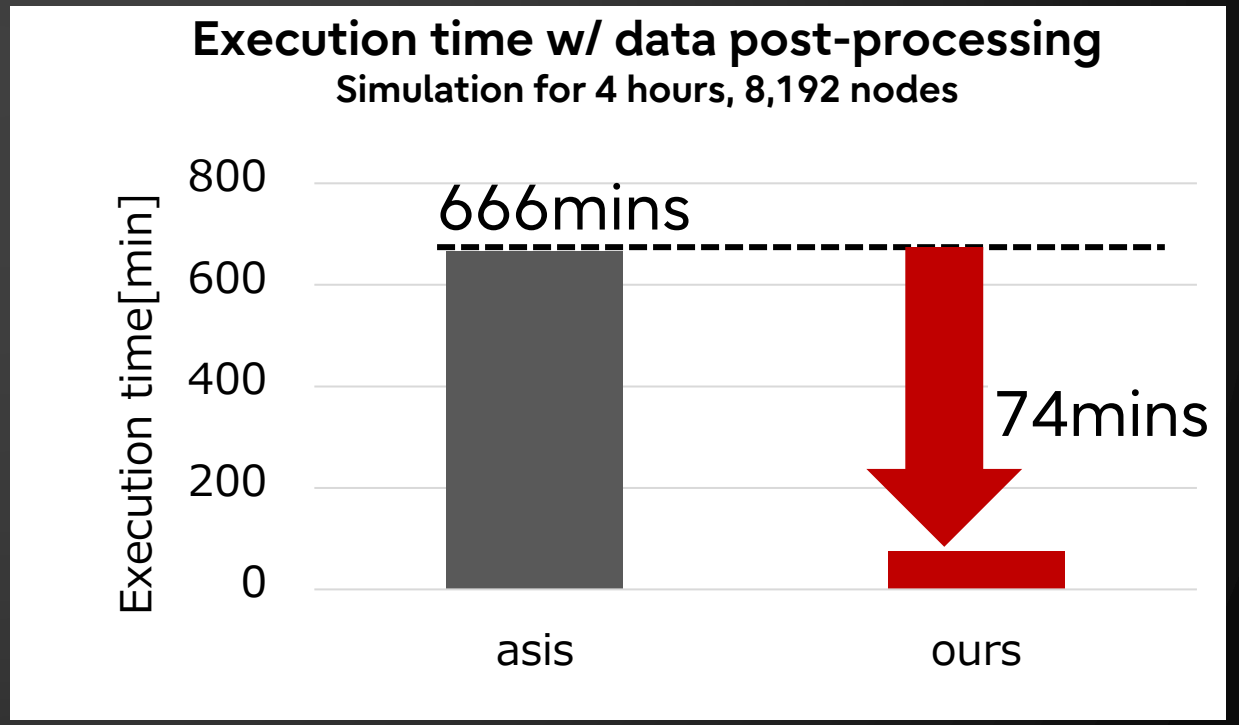


Large-scale parallelization of CReSS: Performance gain

- High parallelization in simulations using thousands of nodes
- Achieves 9x faster and complete a simulation for 4 hours in 74 mins

➡ Enabling tornado prediction with typhoons

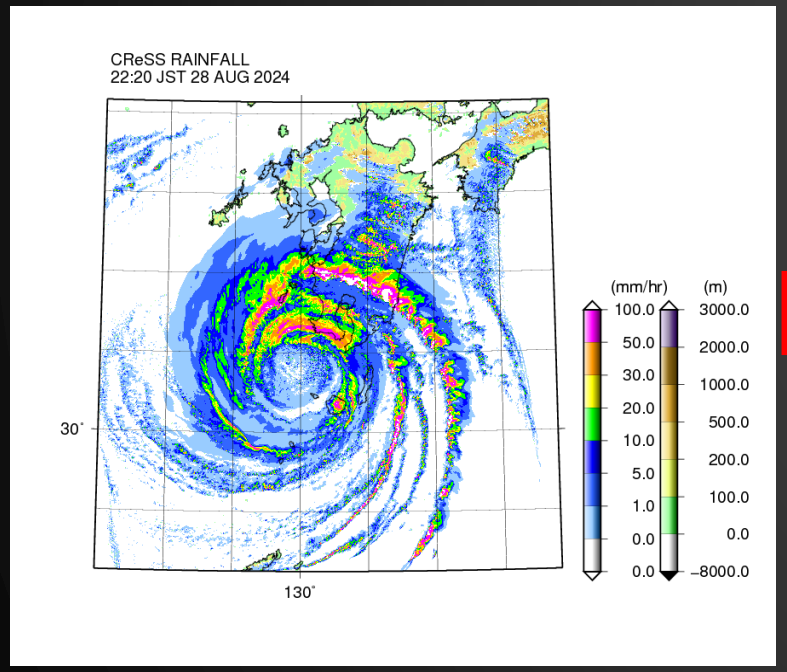




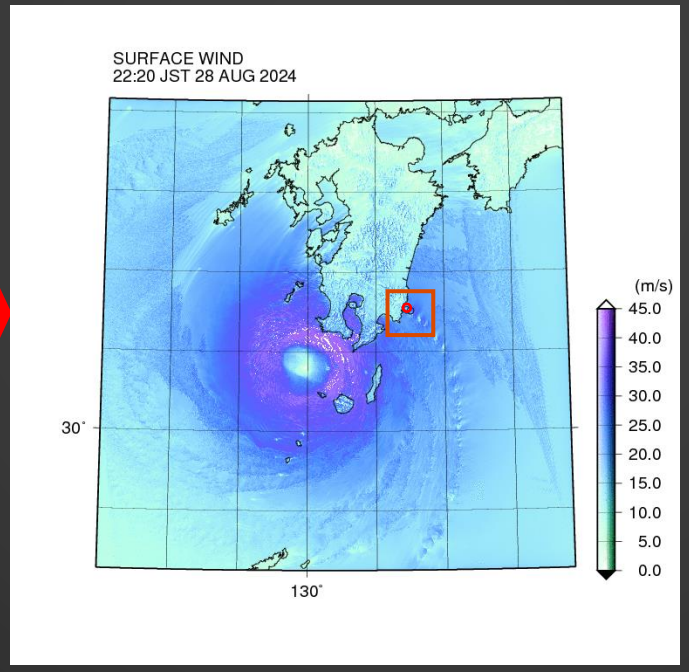
Reproduction of tornadoes with typhoon Shanshan 2024

1. Comparison of our result with observed data
2. Strong vortex-like winds across the typhoon
3. Tornadoes develop in south-east Kyushu

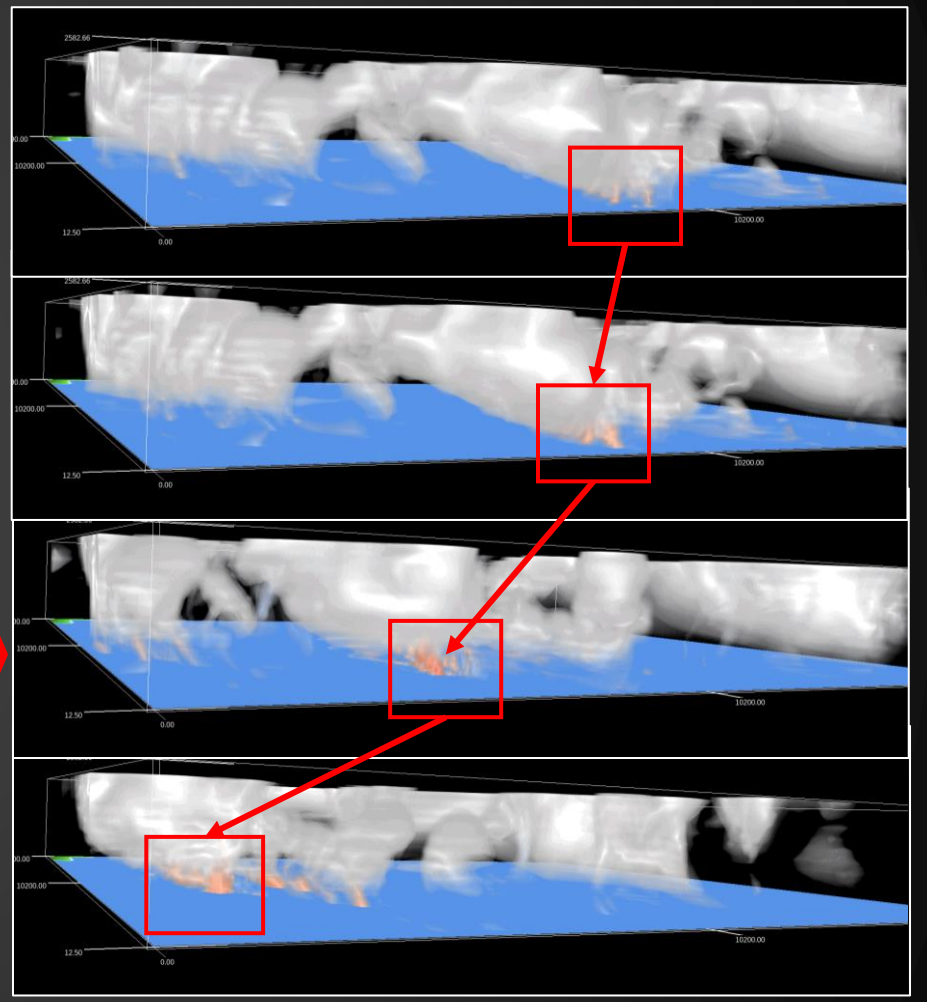
First achieved with an 80-meter horizontal resolution simulation of the entire typhoon



1．Rainfall across the typhoon



2．Generation of vortex-like strong winds

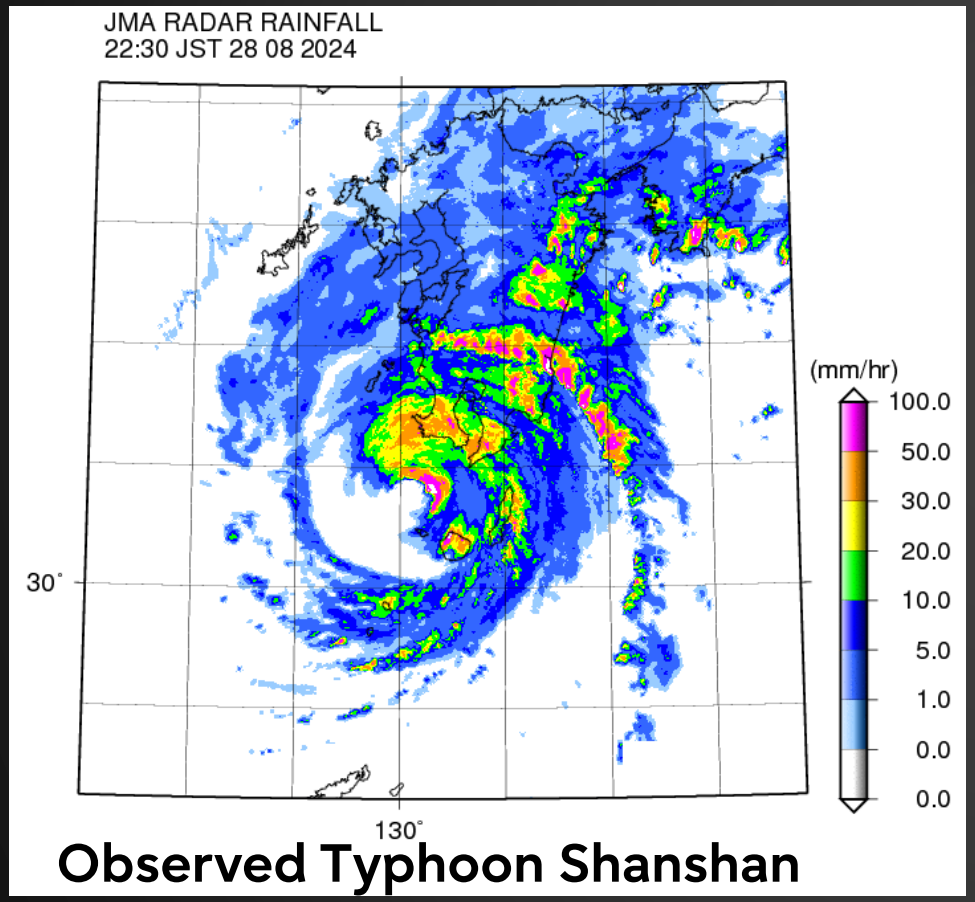


3．Tornadoes develop in south-east Kyushu

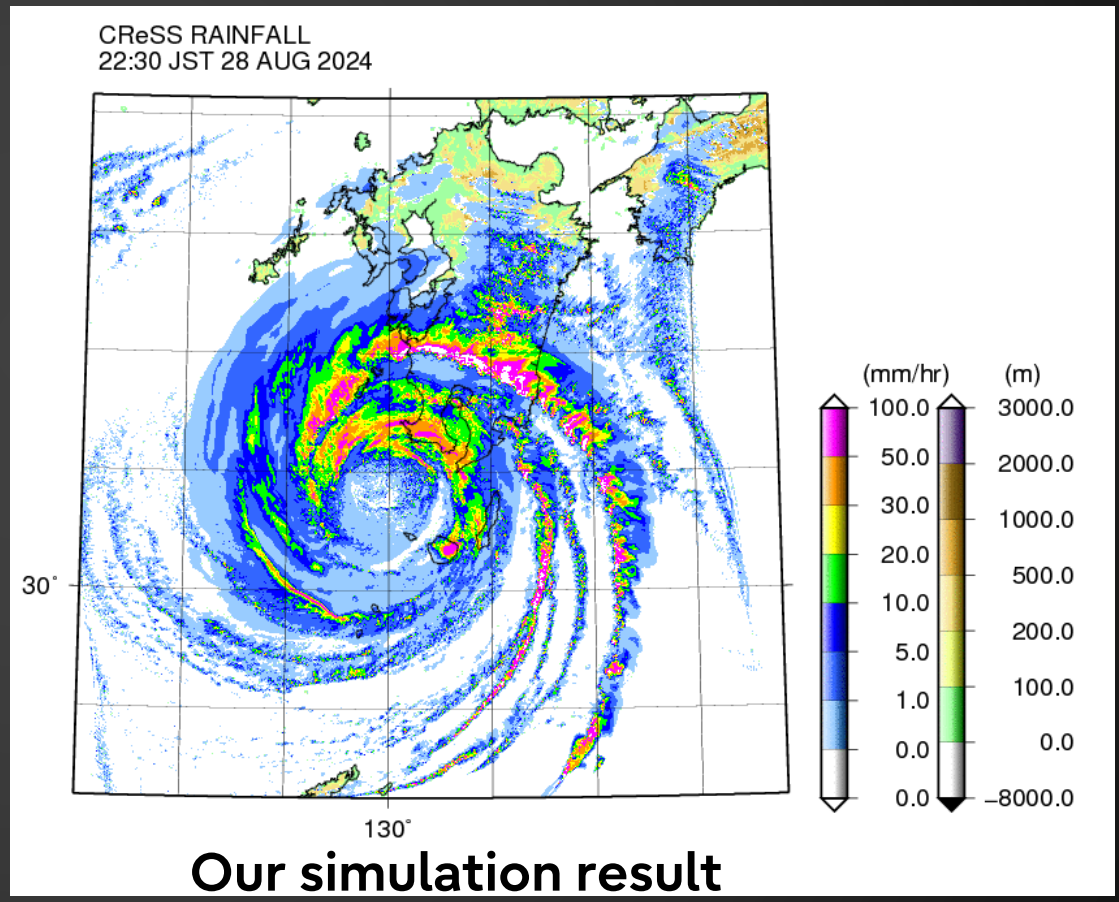
This video is visualized by Yokohama National University using VAPOR
VAPOR : https://www.vapor.ucar.edu

Simulation of Typhoon Shanshan(No.10, 2024)

Rainfall when landing on Kyushu



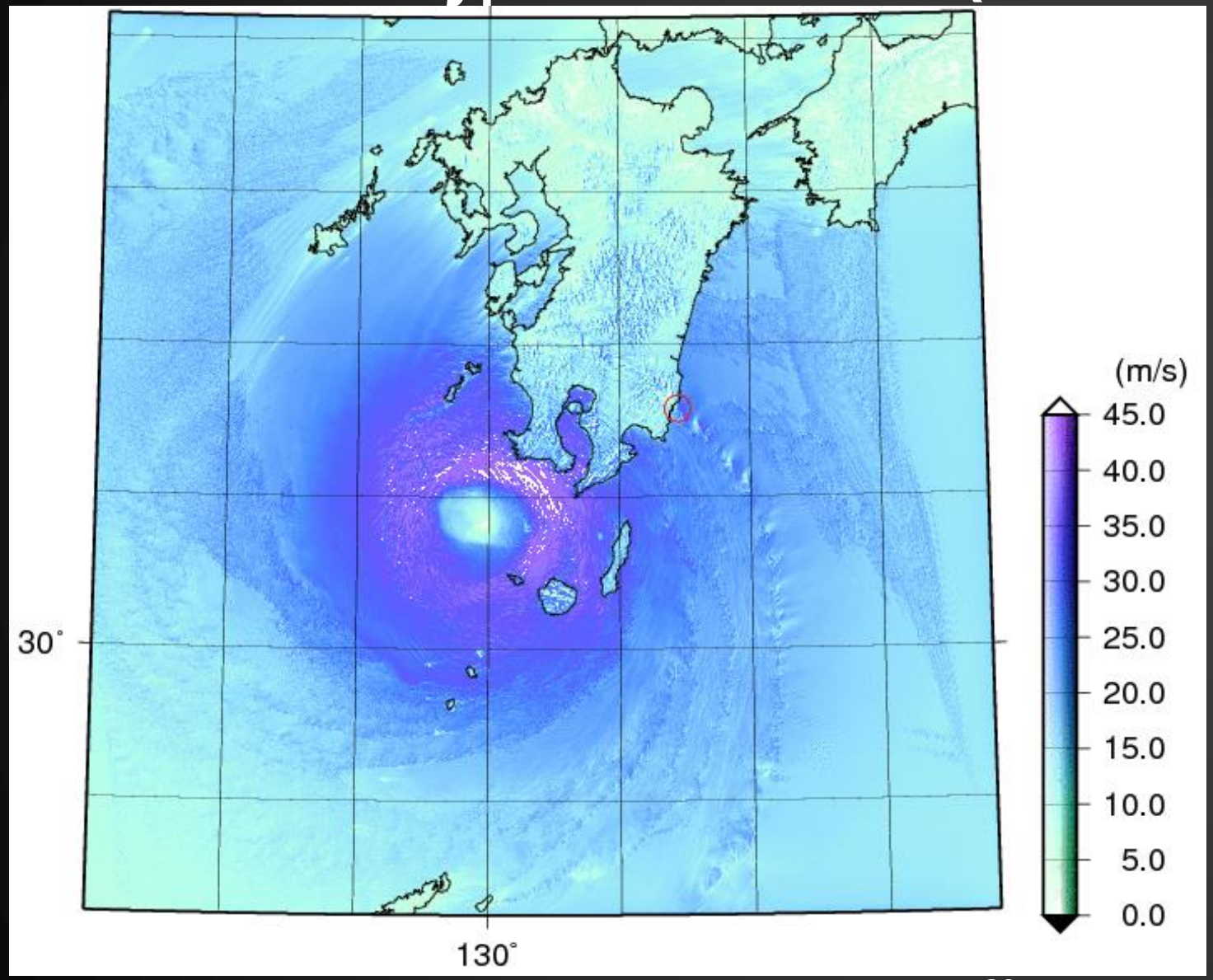
Observed Typhoon Shanshan



Our simulation result

Based on JMA national composite radar GPV
https://www.jmbsc.or.jp/jp/online/file/f-online30110.html

Simulation of Typhoon Shanshan(No.10, 2024)



Detected areas of strong vortex-like winds in south-east Kyushu

The left figure shows wind speed

Detected areas of high tornado potential based on wind speed and vorticity ad the ground surface are marked as "○"

Visualization of the area tornadoes appeared

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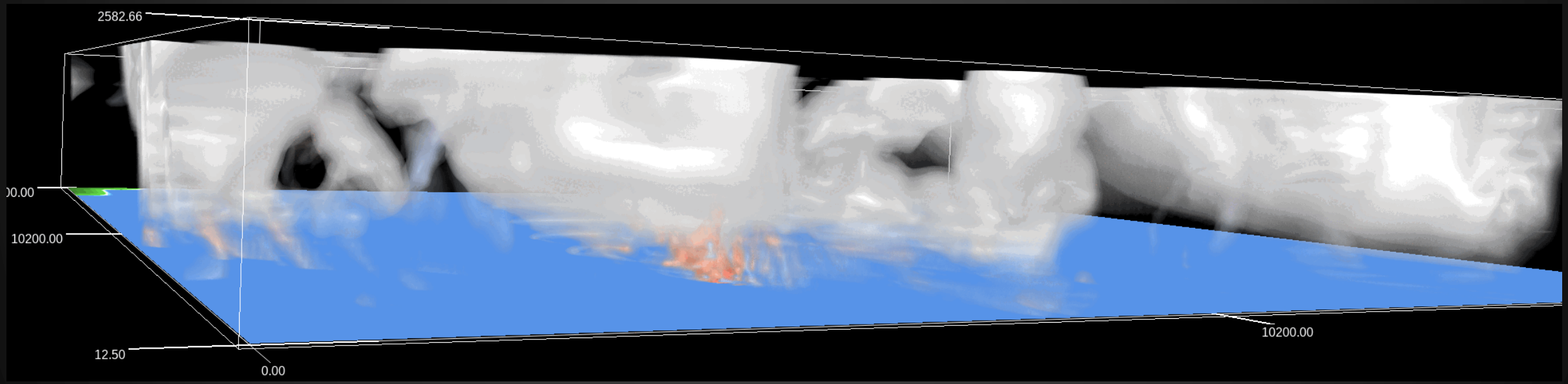
The simulation reproduced a series of tornadoes, moving and developing one after the other



This video is visualized by Yokohama National University using VAPOR
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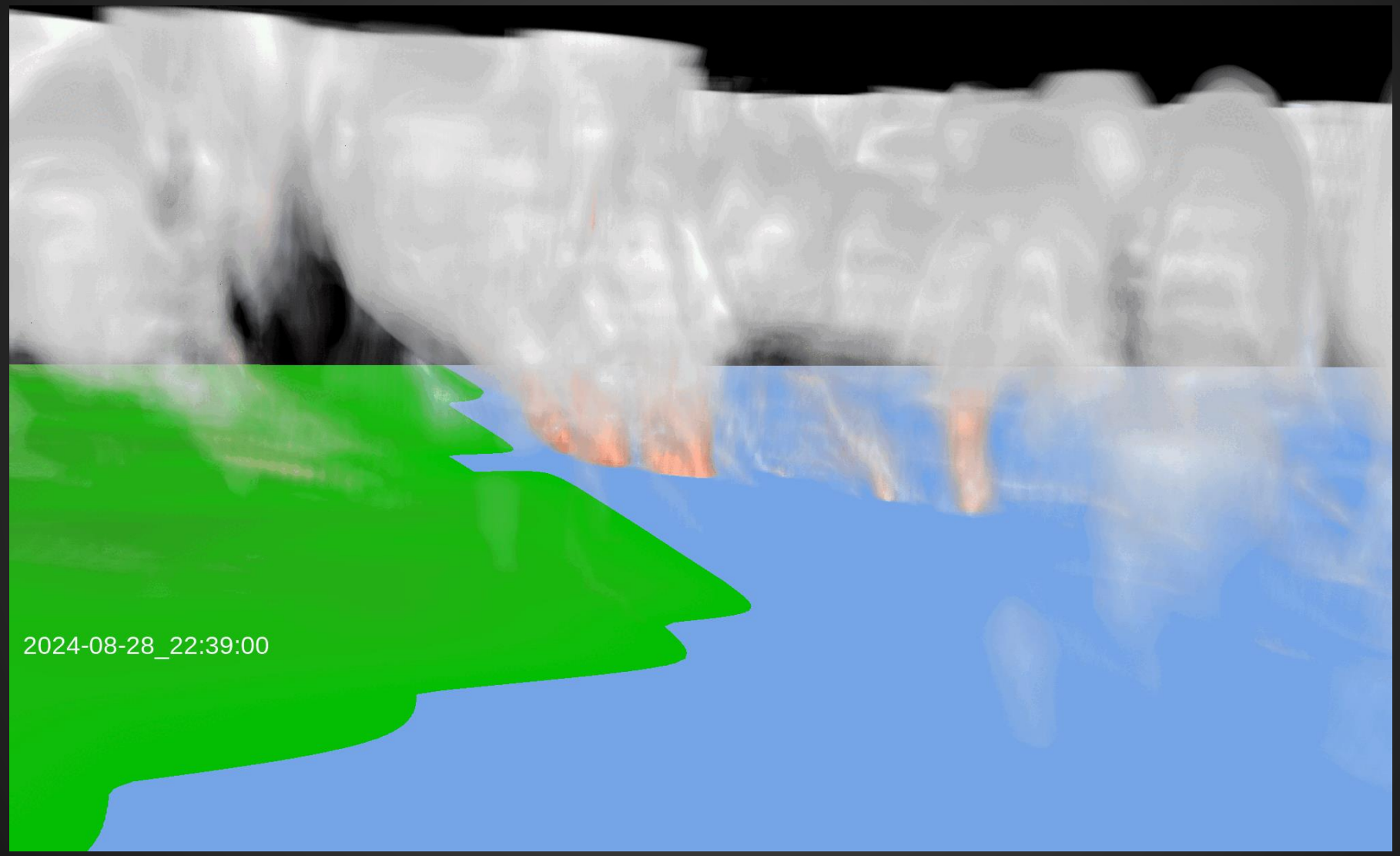
Zoom in on the area around the tornadoes



This video is visualized by Yokohama National University using VAPOR
VAPOR：https://www.vapor.ucar.edu

In the future

- **Upstreaming our optimized version to CReSS**
  - Release this version, optimized for large-scale parallel processing systems, to the research community within this fiscal year
- **Toward solving global environmental problems**
  - Jointly advance research to predict and mitigate the damage caused by tornadoes and heavy rain associated with typhoons by using AI technology to improve accuracy and further accelerate simulation speed
  - Aim to contribute to the solution of global environmental issues, one of Fujitsu’s materiality

Thank you