- Introduction -

The Latest Model Simulation and Observational Studies related to Tropical Cyclone in Japan

Technical Presentation

49th Session of the Typhoon Committee

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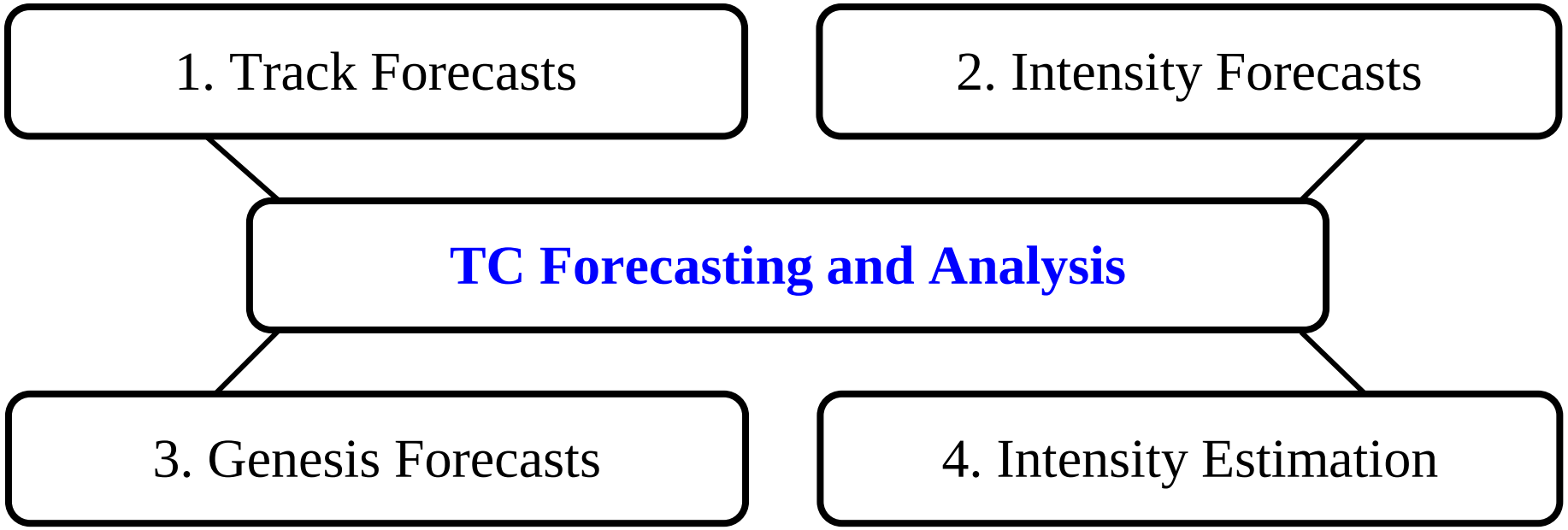
Outline of the talk

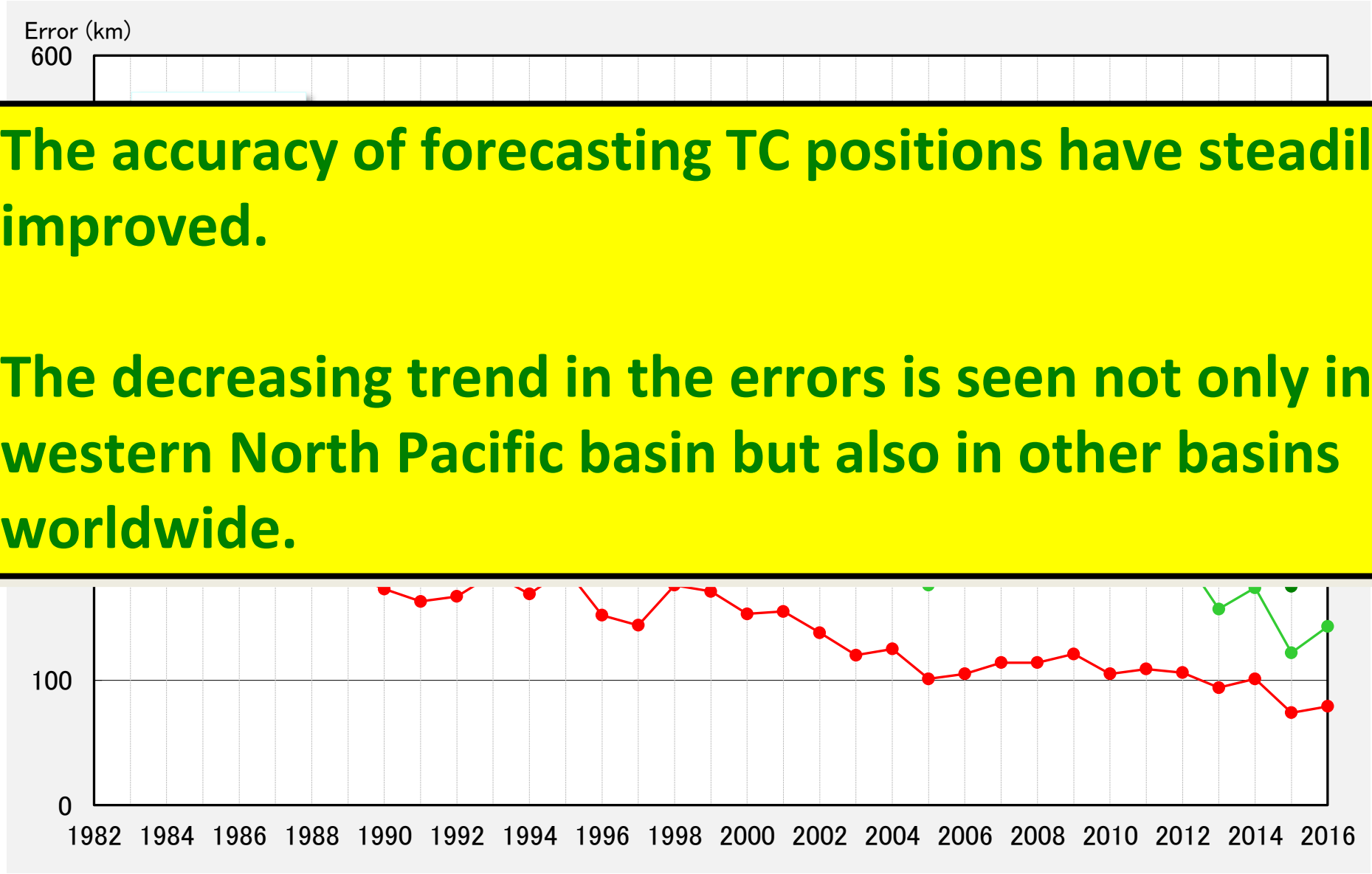
- We will introduce tropical cyclone (TC) research in Japan, focusing mainly on model simulation and observational studies. In the following two presentations, recent research and development activities in Japan to better understand TC dynamics as well as to further improve TC analysis and forecast are presented.
- Before these presentations, **the current status and challenges regarding TC forecasting (Track, Intensity and Genesis Forecasts) and analysis (Intensity Estimation) are briefly overviewed** based on the recommendations at the 8th WMO International Workshop on Tropical Cyclones (IWTC-8) in 2014.



Current Status and Challenges

Track Forecasts

Time Series of the Annual Average Position Errors (km)

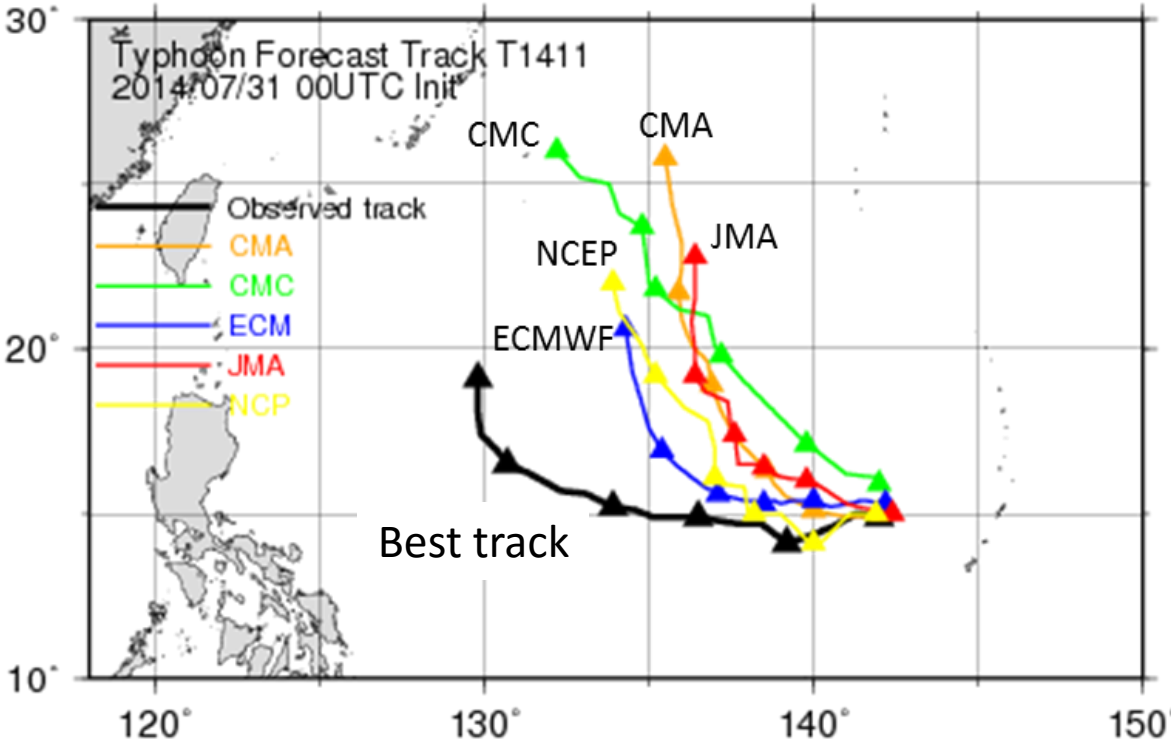


- **The accuracy of forecasting TC positions have steadily improved.**
- **The decreasing trend in the errors is seen not only in the western North Pacific basin but also in other basins worldwide.**

2015 Annual Report on the Activities of the RSMC Tokyo - Typhoon Center

Reduction of forecast bust cases

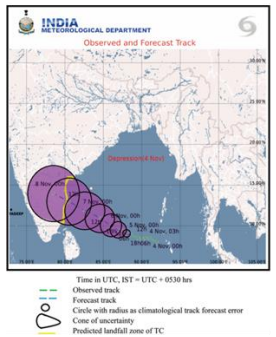
Typhoon Halong (2014)



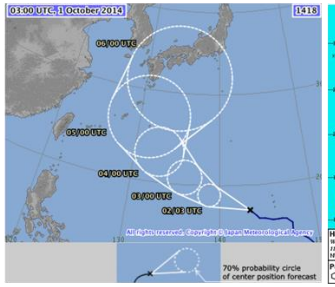
The cause of such a large error should be explored and the NWP systems should be improved accordingly to further strengthen our ability to forecast TC positions.

Enhanced use of ensemble forecasts

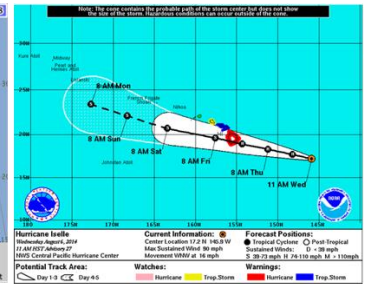
NIO



WNP

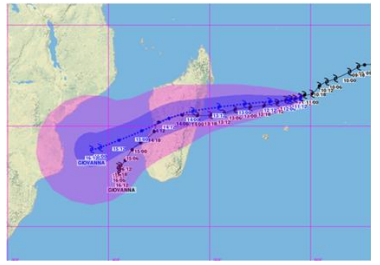


CNP

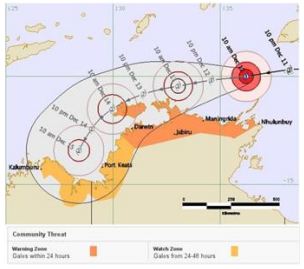


ESP/ATL

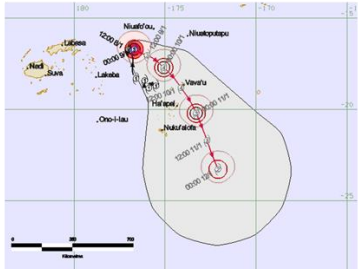
SIO



AUS



SPC

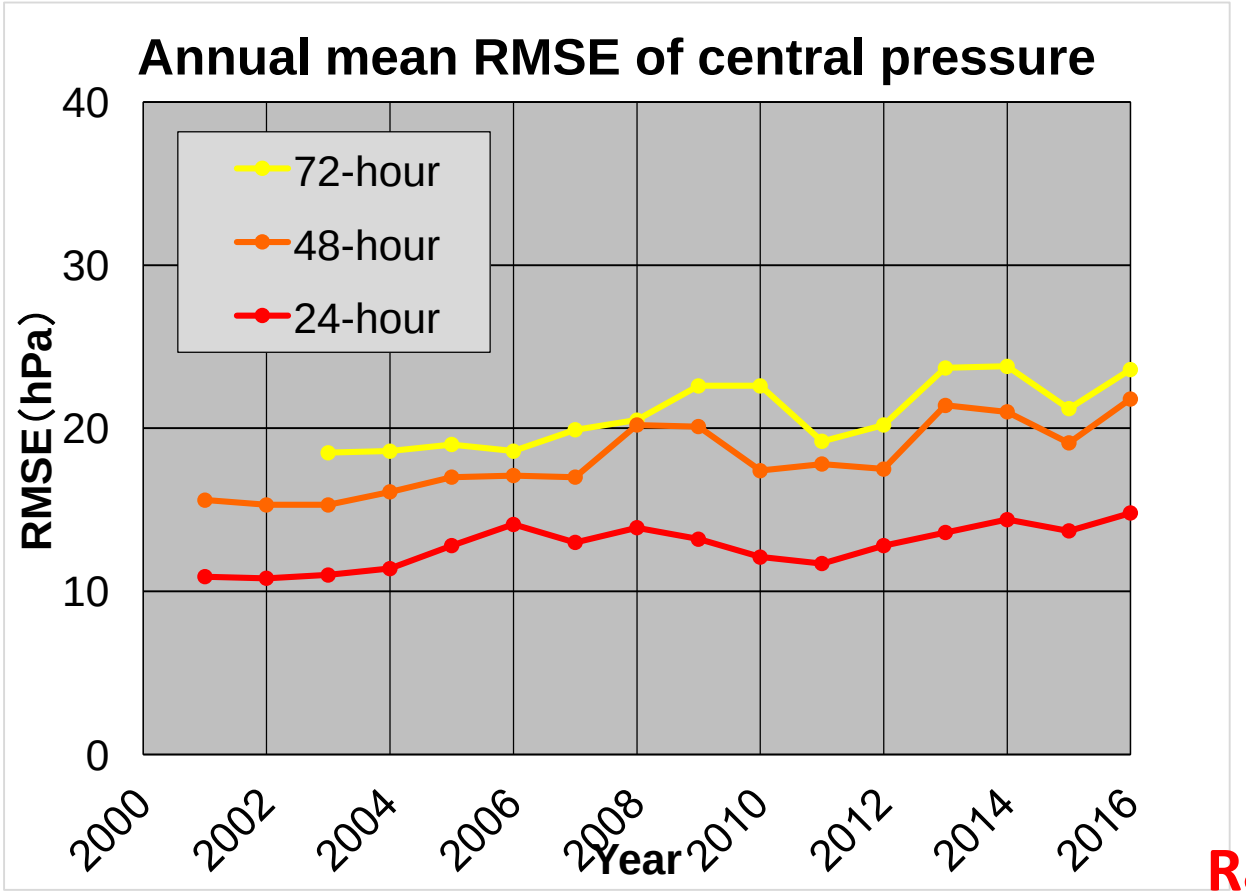


A situation-dependent track forecast confidence display would be more appropriate. Since the TC track is the most fundamental component in issuing warnings, communicating the forecast uncertainty to the public is of great importance.

Current Status and Challenges

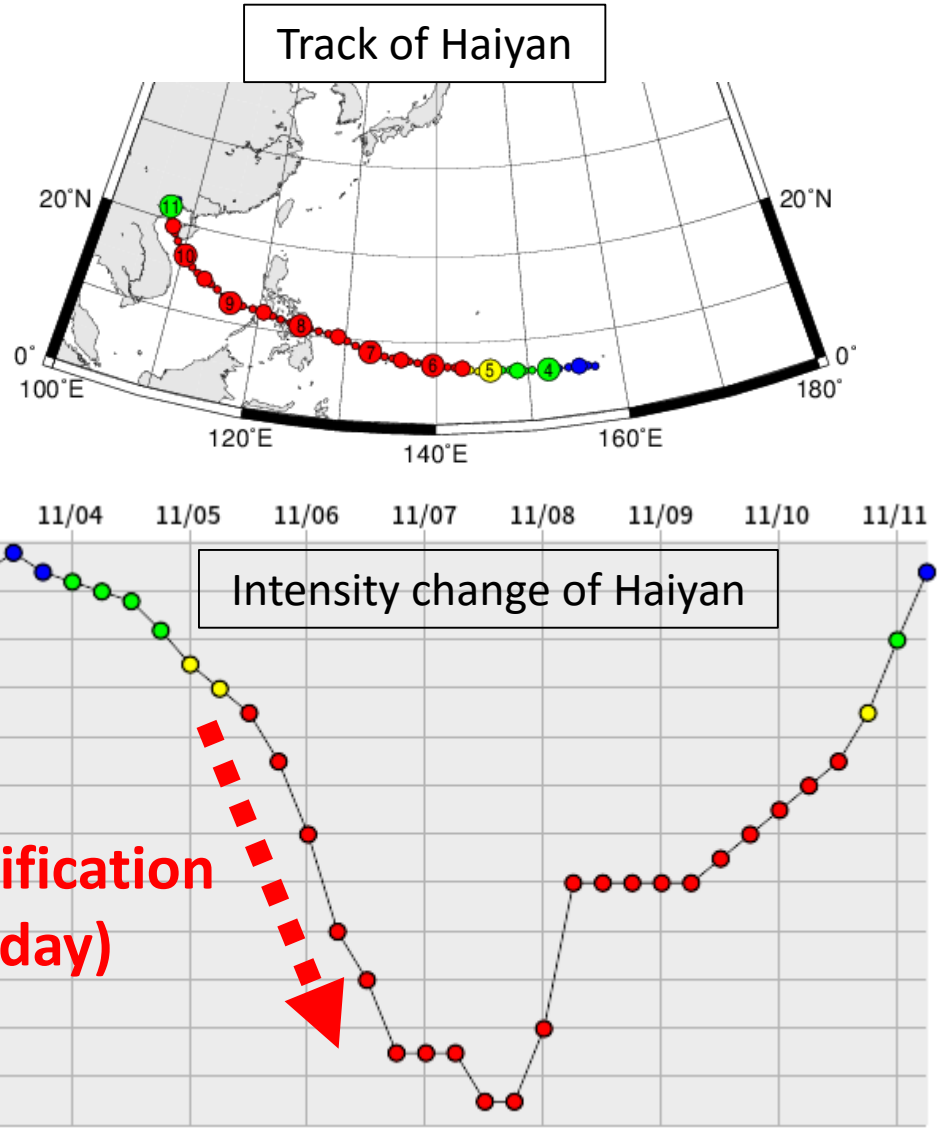
Intensity Forecasts

Time Series of the Annual Average Intensity Errors (hPa)



In contrast to track forecasts, little improvement in intensity forecasts is observed. Forecasting **rapid intensification** of TCs is difficult in particular.

Example of Rapid Intensification Typhoon Haiyan (2013)



Recent Three Studies

Intensity Guidance (DeMaria et al. 2014, BAMS)

They showed the evidence that intensity guidance such as The S… P… h… fo…

x_1, x_2, x_3 … Predictors

α, β, γ: Coefficients

Predictors include

✓Vertical wind shear (850-200 hPa, other levels)

✓Shear direction

✓SST

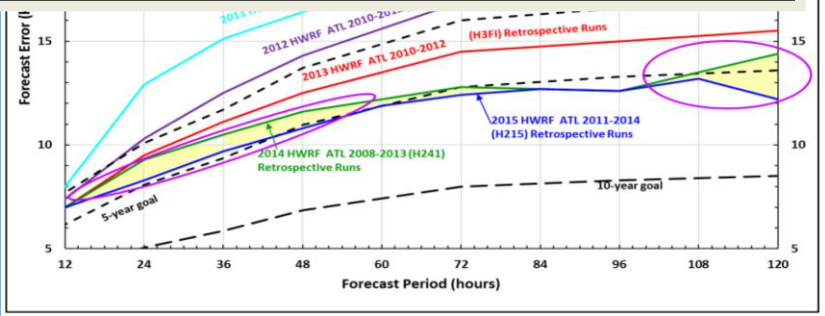
✓Maximum potential intensity and so on…

Assimilation of Aircraft Observations (Zhang and Weng 2015, BAMS)

They showed the errors in forecast intensity for lead times of 2 to 4 days were 25%–28% less than the corresponding official forecasts issued by NHC by assimilating airborne Doppler radar observations.

The Hurricane Forecast Improvement Project (HFIP, Gall et al. 2013, BAMS)

The accuracy of TC intensity forecasts by numerical models such



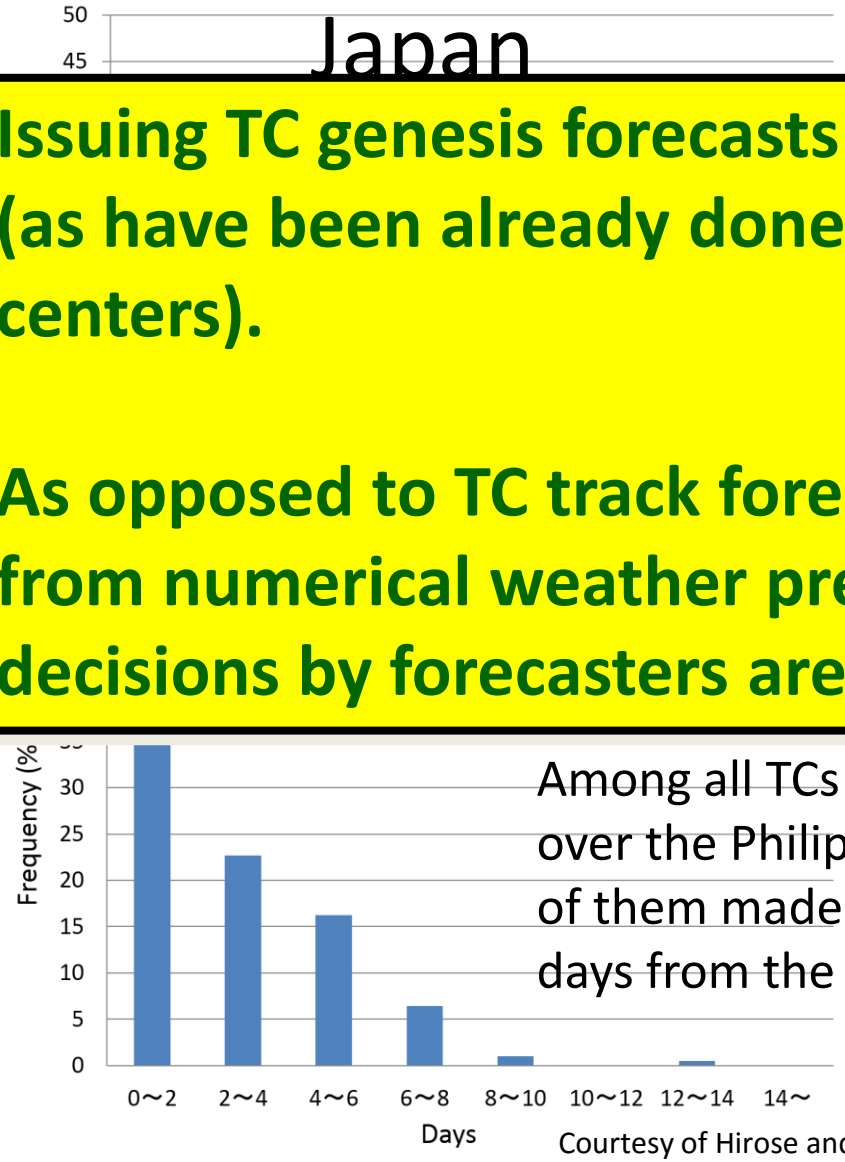
From HFIP 2015 Annual Report

- **Even with these great effort and progress, forecasting TC intensity accurately still remains a challenge for both TC research and forecasting communities.**
- **Further effort will be needed to better understand TC dynamics and thermodynamics associated with TC intensity and its change.**

Current Status and Challenges

Genesis Forecasts

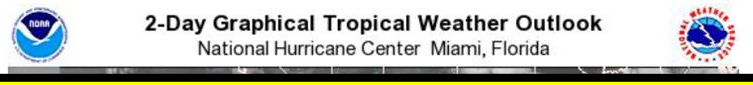
Frequency of Days from TC genesis to the Landfall



Among all TCs that made landfall over the Philippines, about 50 % of them made landfall within 2 days from the genesis.

Courtesy of Hirose and Fudeyasu (Yokohama National Univ.)

Example of 2- and 5-day TC Genesis Forecast at NHC



- **Issuing TC genesis forecasts up to 2 to 5 days ahead will become a standard (as have been already done for track and intensity in most operational centers).**

- **As opposed to TC track forecasting, which heavily relies on the outputs from numerical weather prediction (NWP) models, subjective analyses and decisions by forecasters are more involved in TC genesis forecasts.**

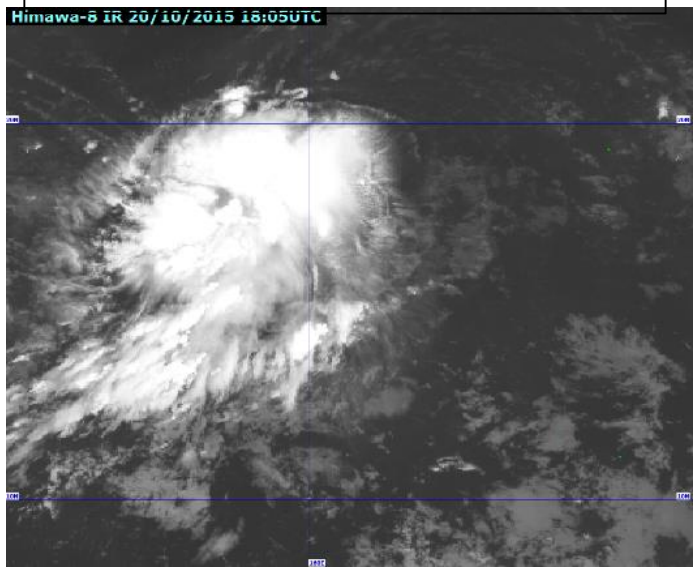
Tropical Cyclone Formation Potential for the 5-Day Period Ending 5:00 am PDT Fri Aug 1 2014
Chance of Cyclone Formation in 5 Days: Low < 30% Medium 30-50% High > 50%
X indicates current disturbance location; shading indicates potential formation area.

Recent Three Studies

Statistical Method (Cossuth et al. 2013, WAF)

They investigated the likelihood of TC genesis based on Dvorak analyses.

Tropical disturbance that was analyzed with T-Number 1.0

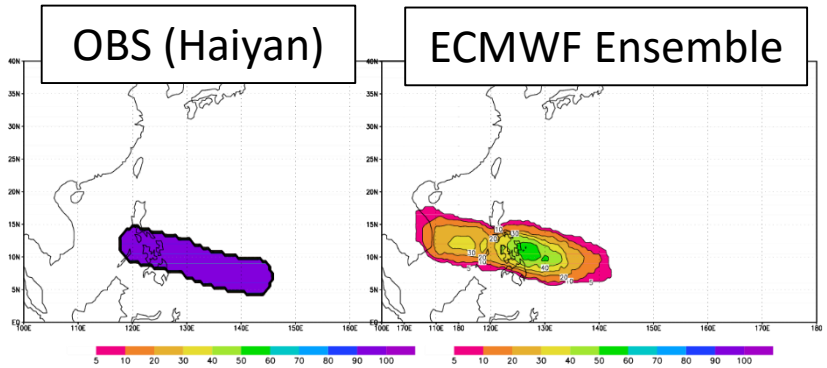


What is the probability that a tropical disturbance with T-Number 1.0 reaches a tropical storm intensity within 2 days?

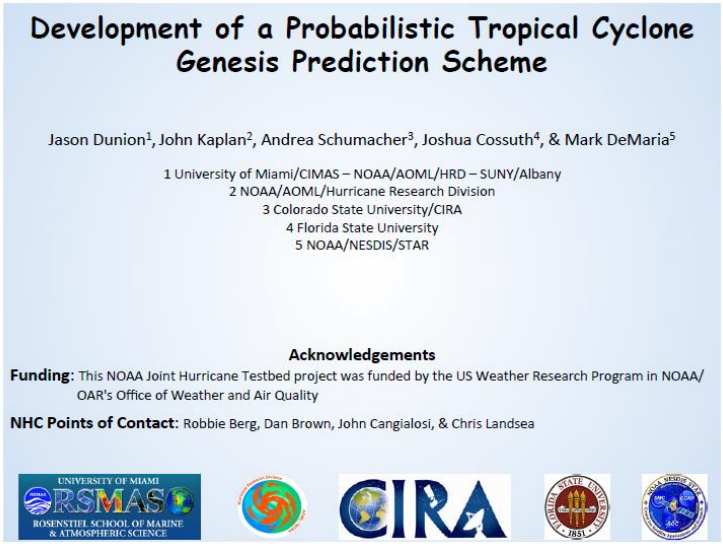
Numerical Prediction-based Method (Yamaguchi et al. 2015, WAF)

They have demonstrated operational global medium-range ensembles are capable of providing skillful guidance of TC activity forecasts with a forecast lead time extending into week 2.

Initial time of the forecasts: 2013/10/31 12 UTC (about **4 days before the genesis** and **8 days before the landfall** over the Philippines)



Statistical-Dynamical Method (Dunion et al. 2013, JHT report)



Development of a Probabilistic Tropical Cyclone Genesis Prediction Scheme

Jason Dunion[1], John Kaplan[2], Andrea Schumacher[3], Joshua Cossuth[4], & Mark DeMaria[5]

1 University of Miami/CIMAS – NOAA/AOML/HRD – SUNY/Albany
2 NOAA/AOML/Hurricane Research Division
3 Colorado State University/CIRA
4 Florida State University
5 NOAA/NESDIS/STAR

Acknowledgements

Funding: This NOAA Joint Hurricane Testbed project was funded by the US Weather Research Program in NOAA/OAR's Office of Weather and Air Quality

NHC Points of Contact: Robbie Berg, Dan Brown, John Cangialosi, & Chris Landsea

They have developed an objective tool for identifying the 2- and 5-day probability of TC genesis and showed the effectiveness of the guidance over climatological forecasts.

Current Status and Challenges

Intensity Estimation

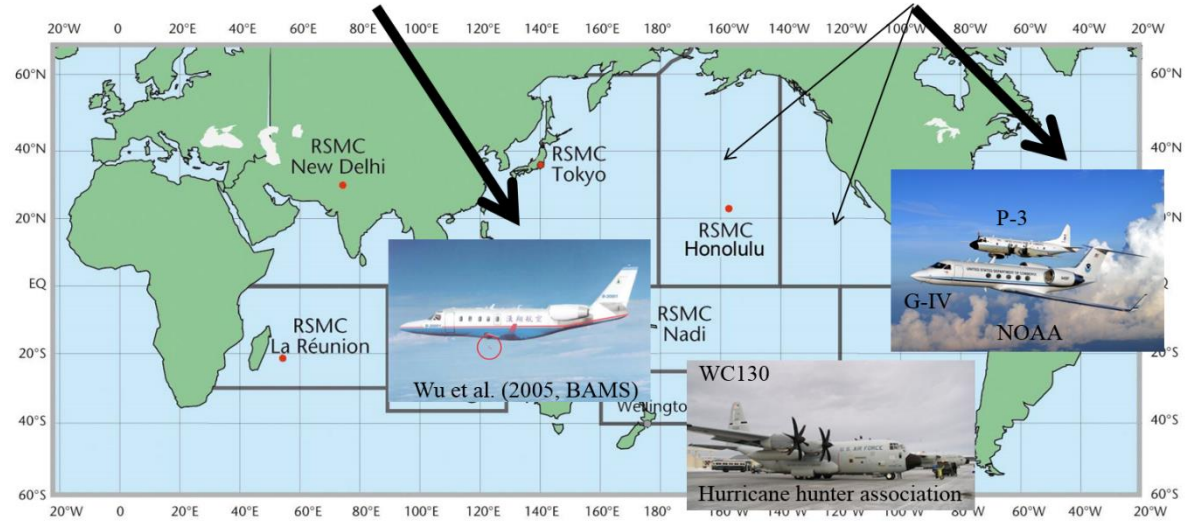
Dvorak Technique

This is a method to estimate TC intensity based on geostationary satellite images. All the RSMCs and TCWCs use the Dvorak technique to estimate TC intensity.

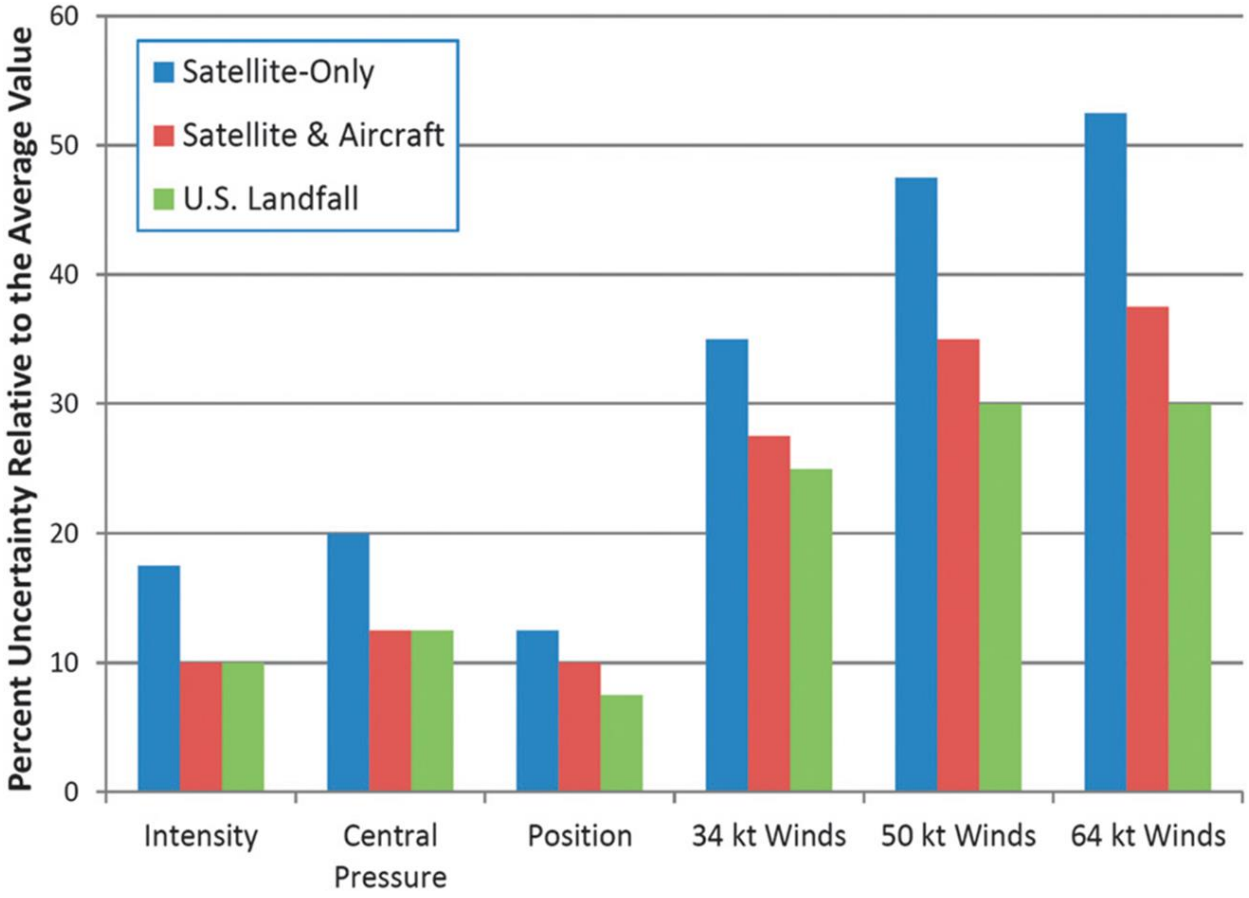
Aircraft Observations

DOTSTAR
(NTU, CWB, TTFRI etc)
Aircraft: ASTRA SPX

Hurricane Hunters
(US Air Force and NOAA)
Aircraft: WC130, P-3, G-IV



Landsea and Franklin (2013, MWR)



The uncertainty in estimating TC intensity, position and size significantly decreases by using aircraft observations.

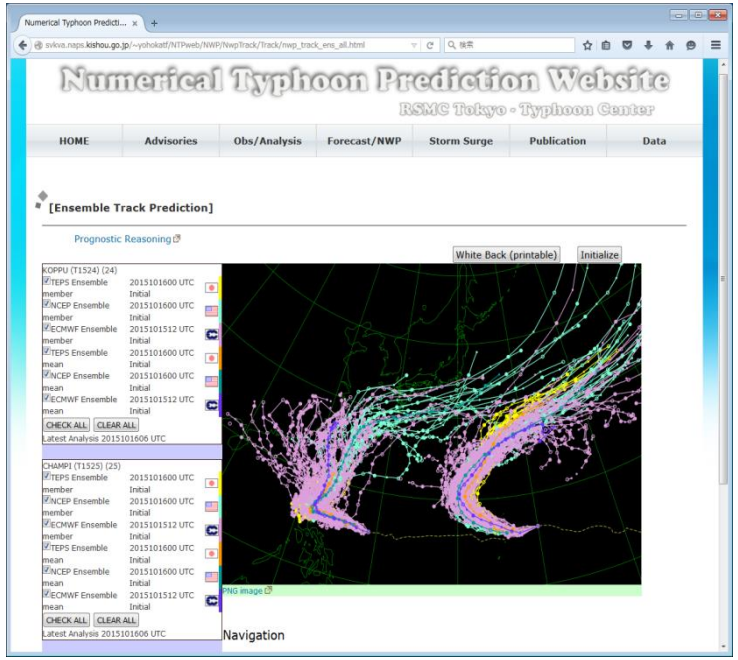
Recent studies on this topic will be presented by Dr. Yamada in detail.

Future Directions

Three future possible directions

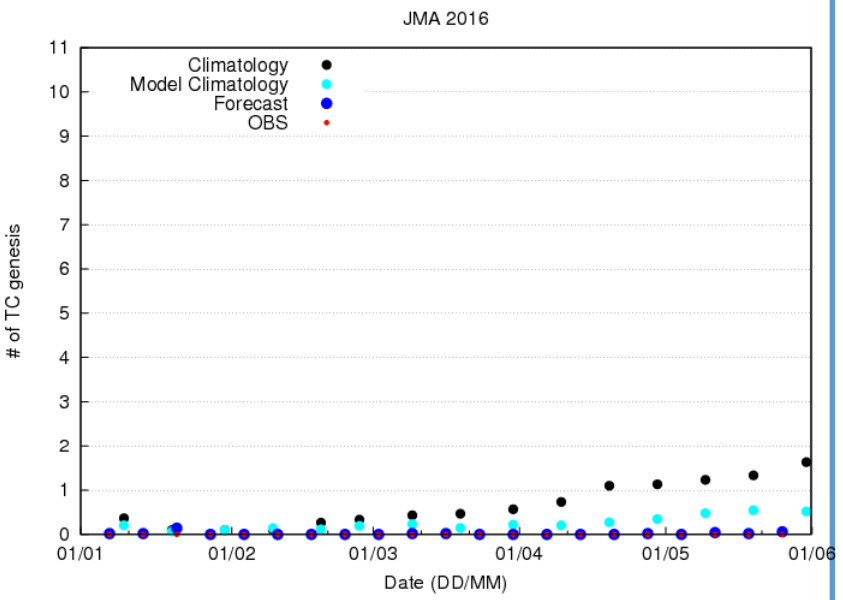
Enhanced use of ensembles

There will be increasing demand to provide a situation-dependent forecast confidence information from disaster risk reduction perspectives. Transferring research outcomes associated with optimal use of ensemble information to operation is one of our challenges.



Long-term prediction and predictability study

The operational medium-range and 1-month ensembles are freely available under the WMO/WWRP-supported TIGGE and S2S archives.



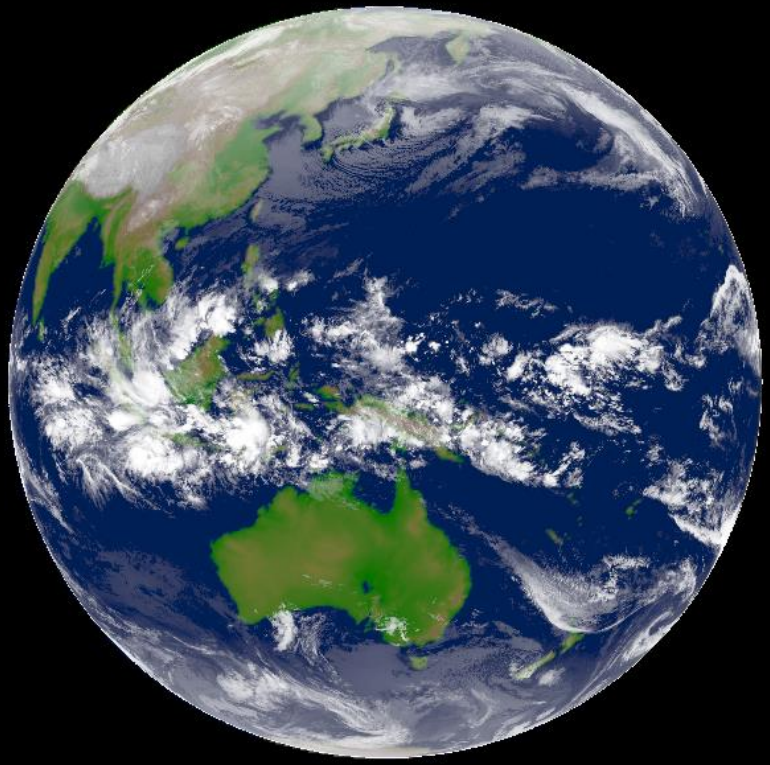
Inactivity of TCs in early 2016 was well predicted in a month ensemble.

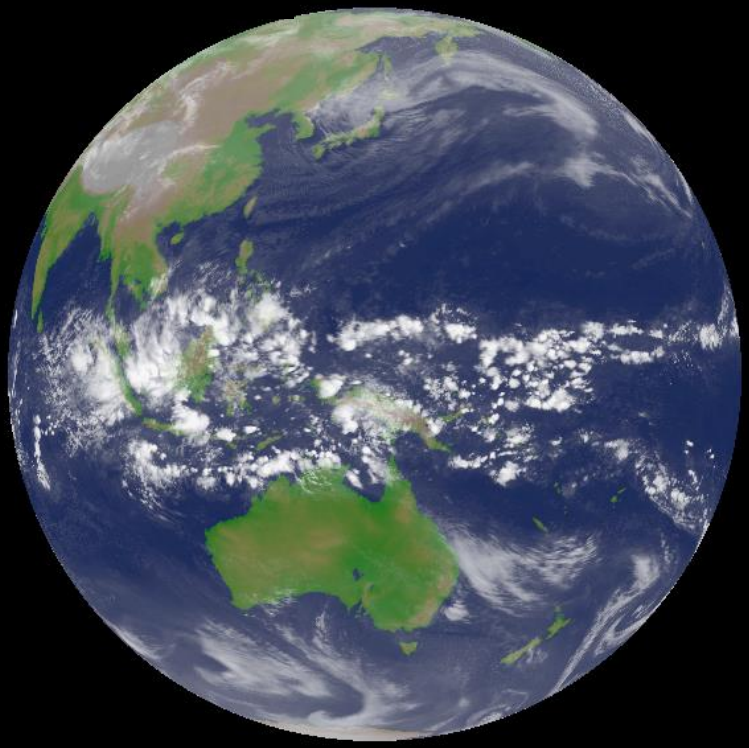
Improvement in prediction of disaster-related weather components

From THORPEX Science Plan

As disasters associated with TCs result from damaging winds, heavy rainfall, storm surge and so on, evaluation of such components in addition to simply verifying track and intensity of TCs will be of great importance.

Tropical Cyclone Research in Japan
Model Simulation Studies





Hironori FUDEYASU, Yokohama National University

With Thanks to

J. Ito (MRI-JMA), M. Nakano, Y. Yamada (JAMSTEC), M. Satoh (Tokyo Univ.), K. Ito (Ryukyus Univ.), R. Yoshida, H. Tomita Y. Miyamoto (Riken), S. Kanada, M. Kato, S. Tsuboki (Nagoya Univ.), T. Takemi (Kyoto Univ.) ,S. Yamasaki (YNU)

Background

Issues

- **Tropical cyclone (TC) lifecycle, genesis, intensifying, intensity changes, decaying has remained challenging complex studies.**
- **TCs involve interactions among physical processes that vary over the multiple space scale and the time scale.**
- **Model simulation studies contributed to our understanding.**
- **Numerical models are useful tools!**

Key

- **Development of a cloud-resolving Global/Regional models and high-end powerful computers are needed.**

Today's talk is

- **History of super computers and TC model simulation studies.**

Evolution of High-End Super Computers

Evolution of High-End Super Computers in Japan

The 2011 world's fastest computer

K computer

11,280 TFlop/s

The 2002-2004 world's fastest computer

2002 Earth Simulator | 2009 ES2 | 2011 K | 2015 ES3 | NEXT GEN ?

41 TFlop/s

131 TFlop/s

1,310 TFlop/s

CLOCK RATE

Kyoto Univ.

5,483 TFlop/s

Nagoya Univ.

3,244 TFlop/s

Univ. of Tokyo

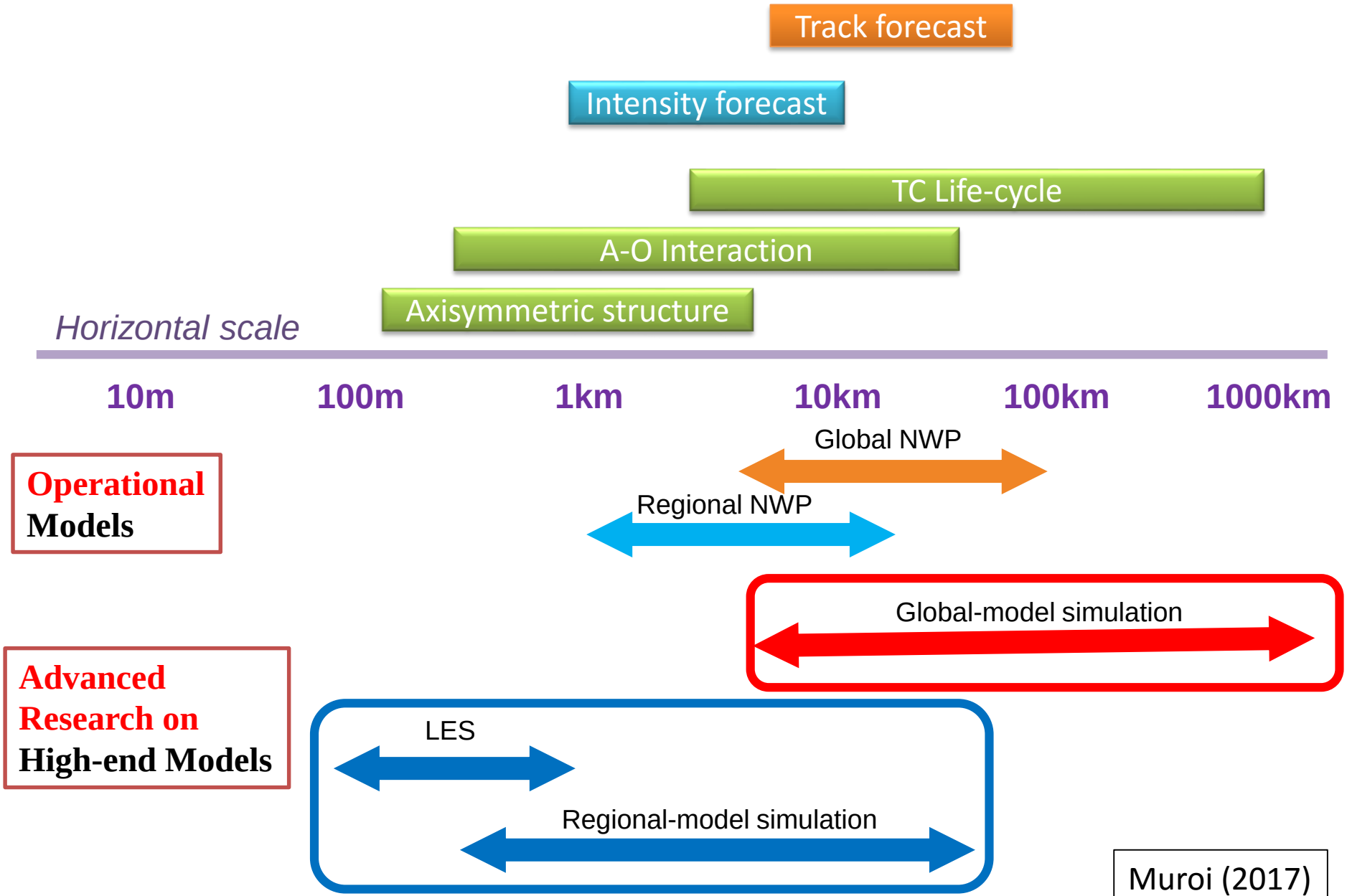
Tsukuba Univ.

24,913 TFlop/s

High-End Super Computers have been evolving rapidly

Model Simulation Studies

Target of model simulations and horizontal scale for TCs



Muroi (2017)

Regional Model Simulation Studies

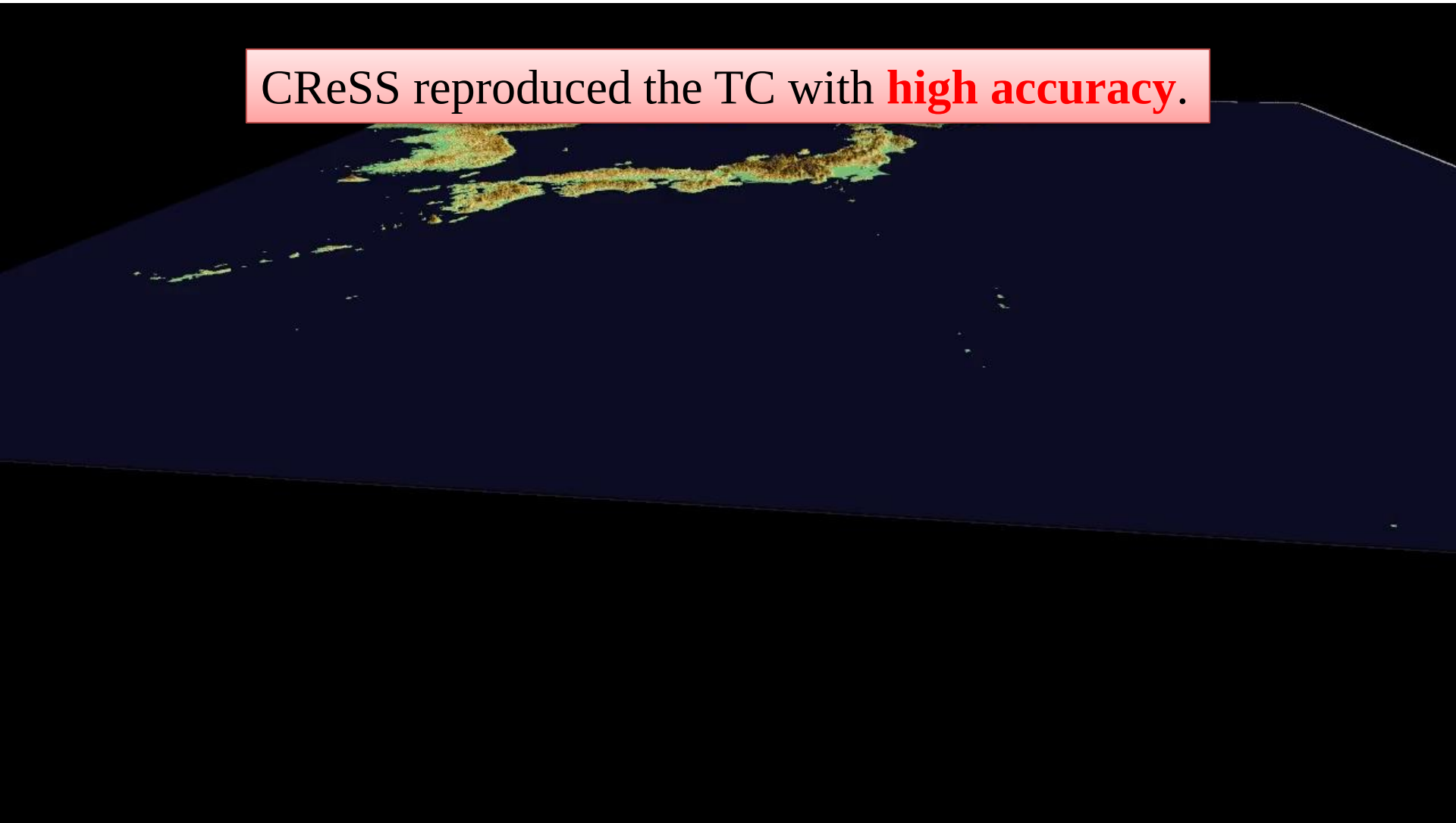
High-resolution regional model

宇宙地球環境研究所
Institute for Space-Earth Environmental Research

CReSS Δx=2km

Cloud Resolving Storm Simulator developed by Nagoya Univ.

Tsuboki et al. (2002) Kato et al. (2017)



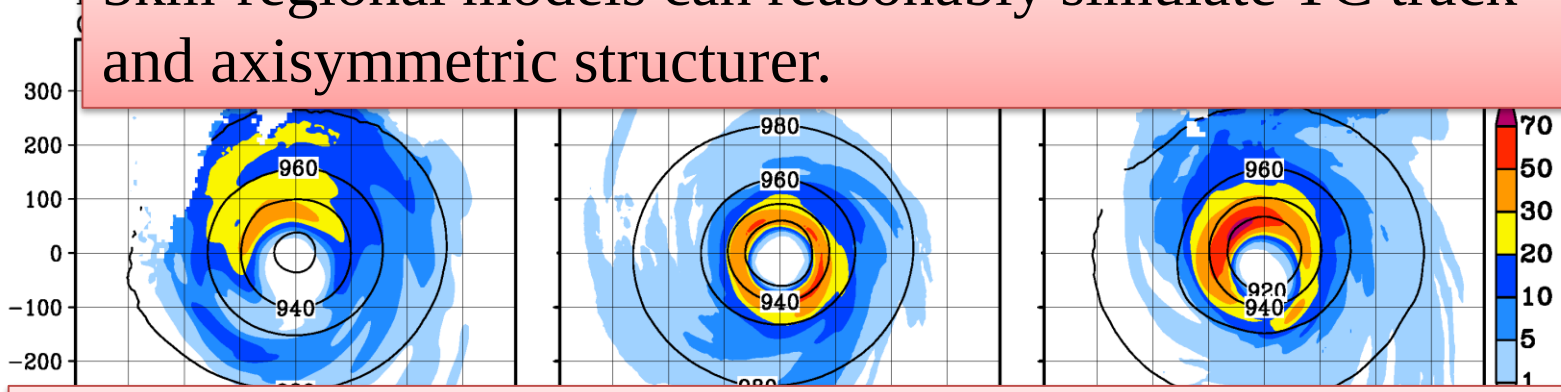
CReSS reproduced the TC with **high accuracy**.

5-km Regional models intercomparison

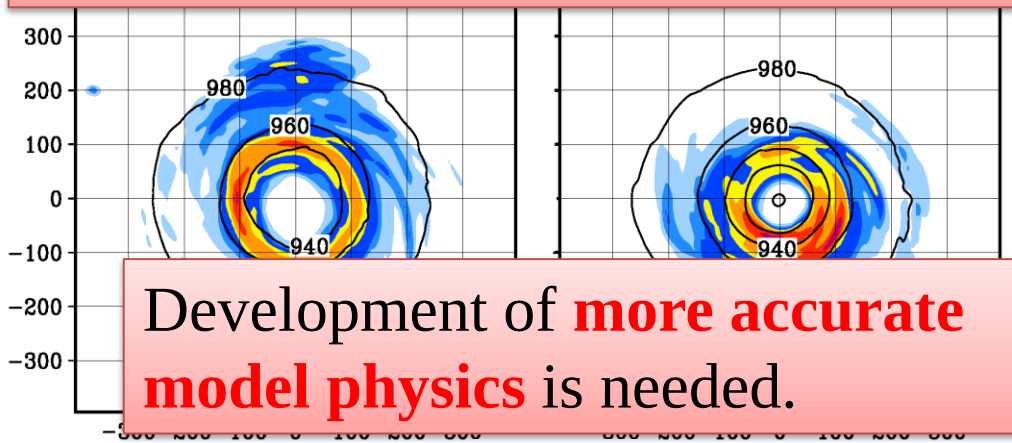
Kanada et al. (2017)

CReSS **JMA-NHM** **MM5**

5km-regional models can reasonably simulate TC track and axisymmetric structurer.

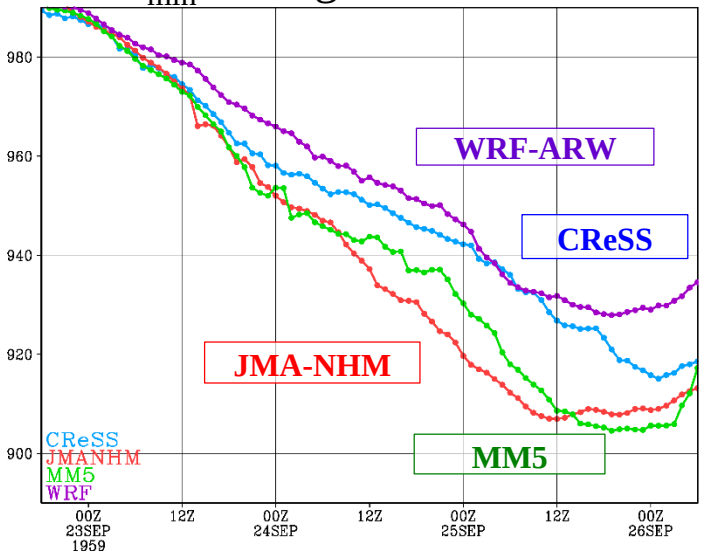


Multi-model experiments show the differences of inner-core structures between the models.



Development of **more accurate model physics** is needed.

P_{min} for regional model TC



WRF-ARW

Δx＝5km

Atmosphere-Ocean coupled model

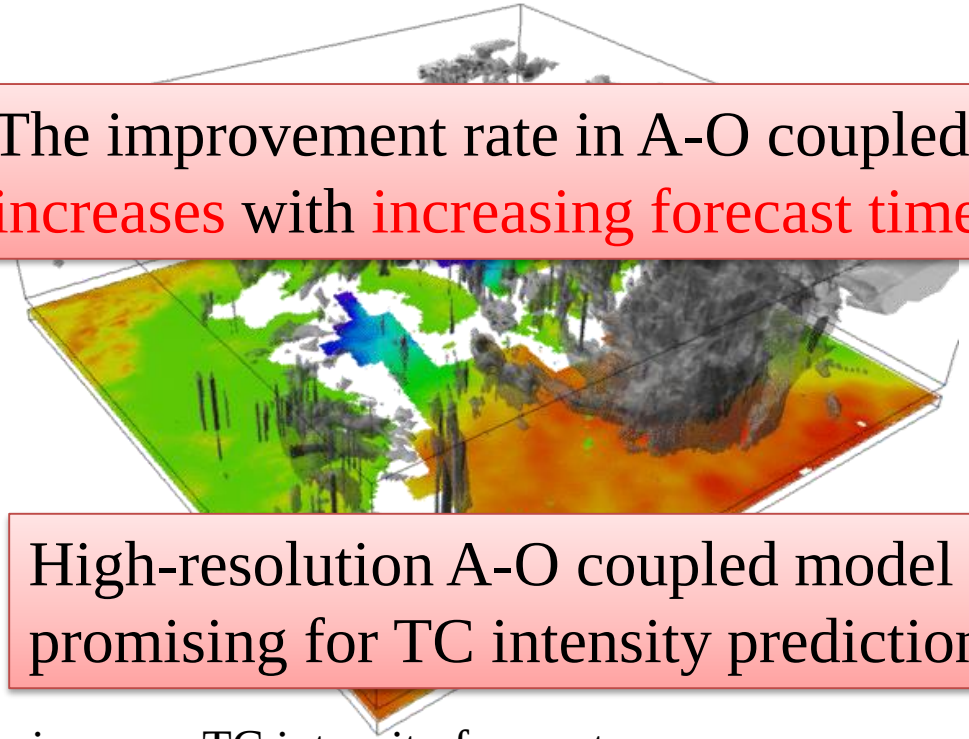
JMA-NHM

JMA nonhydrostatic atmospheric mesoscale model developed by JMA.

Saito et al. (2006)

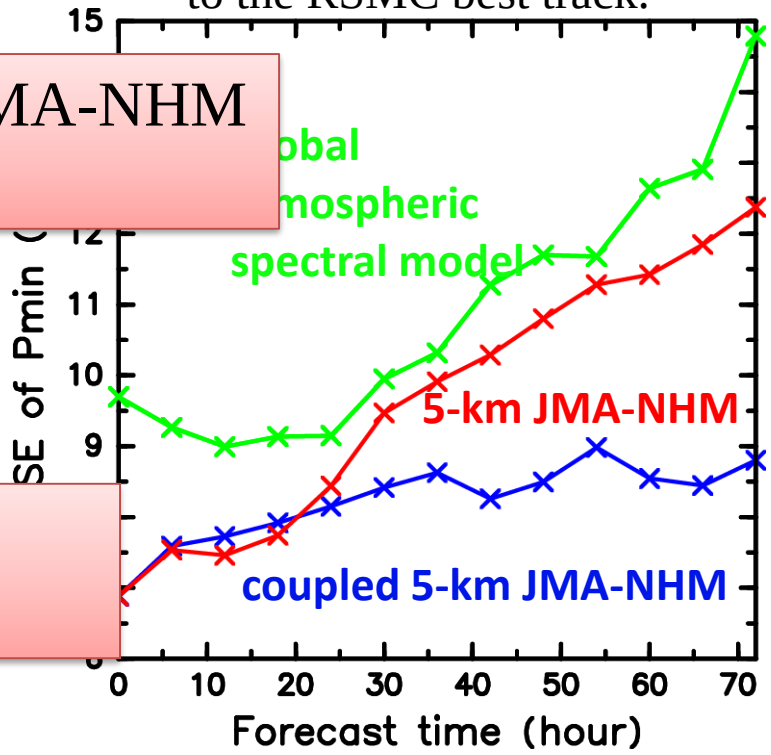
***coupled JMA-NHM*Δx=5km**

Atmosphere–Ocean coupled model



Performance of TC intensity forecast by JAM-NHM

RMSE of P_{min} relative to the RSMC best track.



The improvement rate in A-O coupled JMA-NHM increases with increasing forecast time.

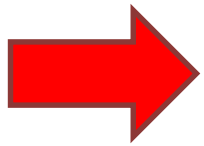
High-resolution A-O coupled model is promising for TC intensity prediction.

To improve TC intensity forecast

Ito et al. (2015)	Ito et al. (2017)	Kunii et al. (2017)

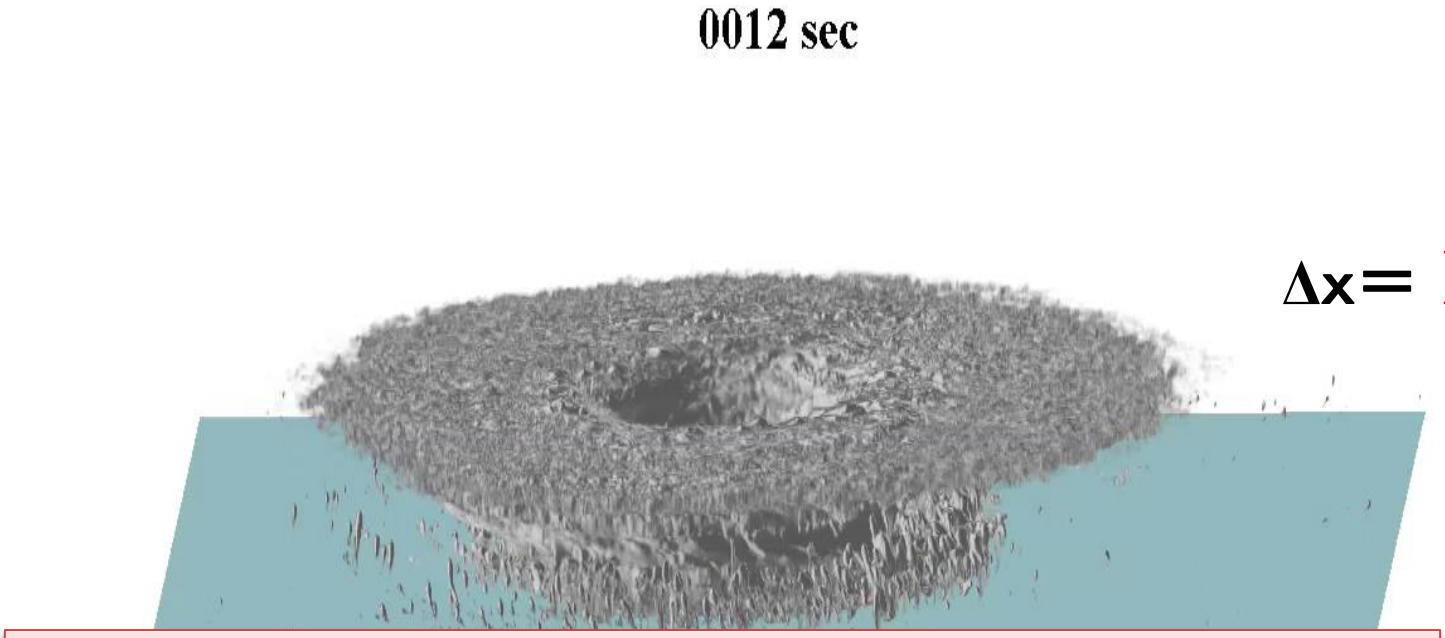
100-m resolution simulation

JMA-NHM
Δx＝2km



Large eddy simulation

K-computer allows us to perform Large eddy simulations of entire TC.



Δx＝ 100 m

Various near-surface roll structures in a TC are found.

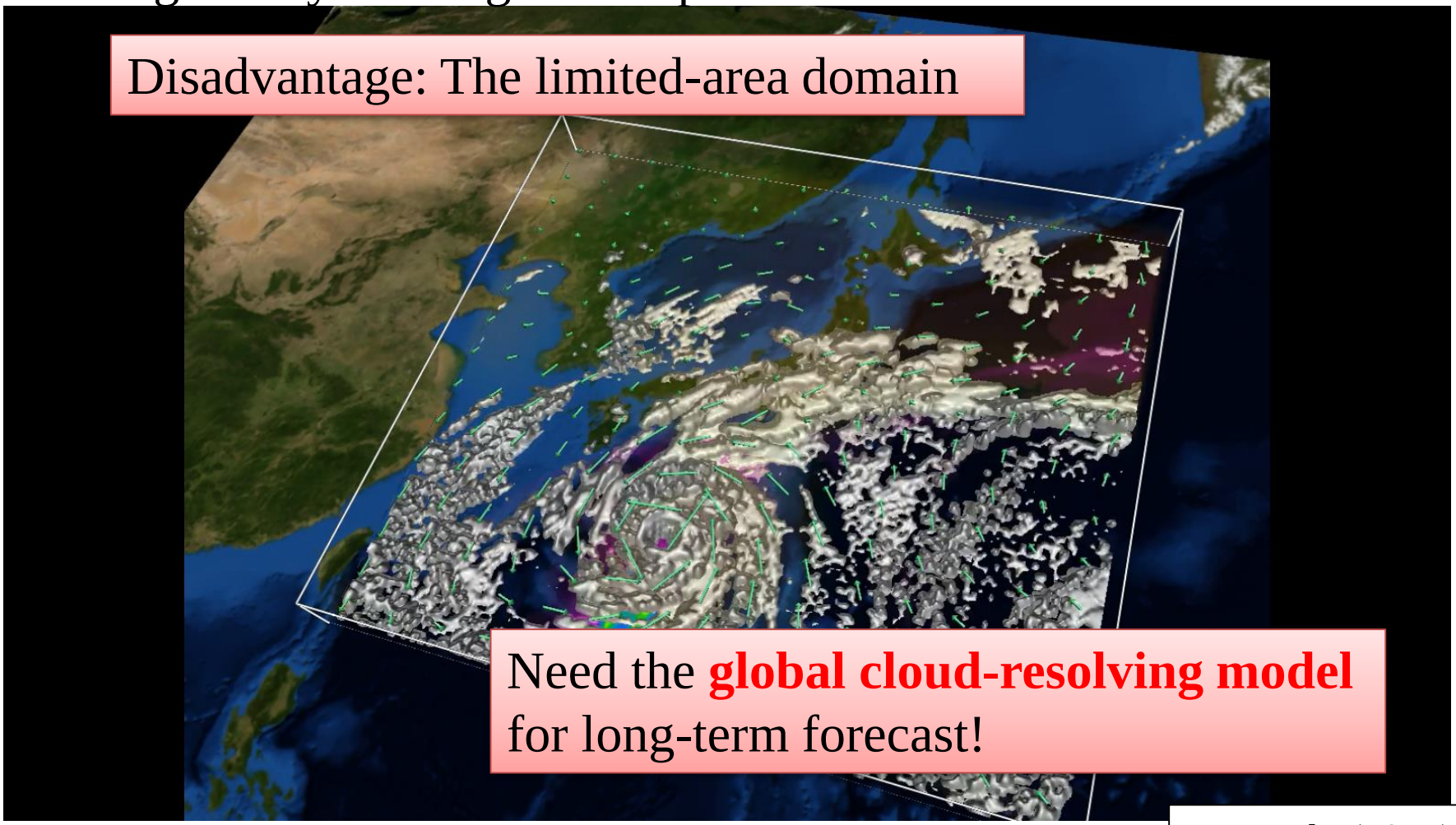
Ito et al. (2017)

Global Model Simulation Studies

Need cloud-resolving global models

High-resolution simulation in the regional models contributed to our understanding on the TC lifecycle.

Advantage: Easy to design the experiments



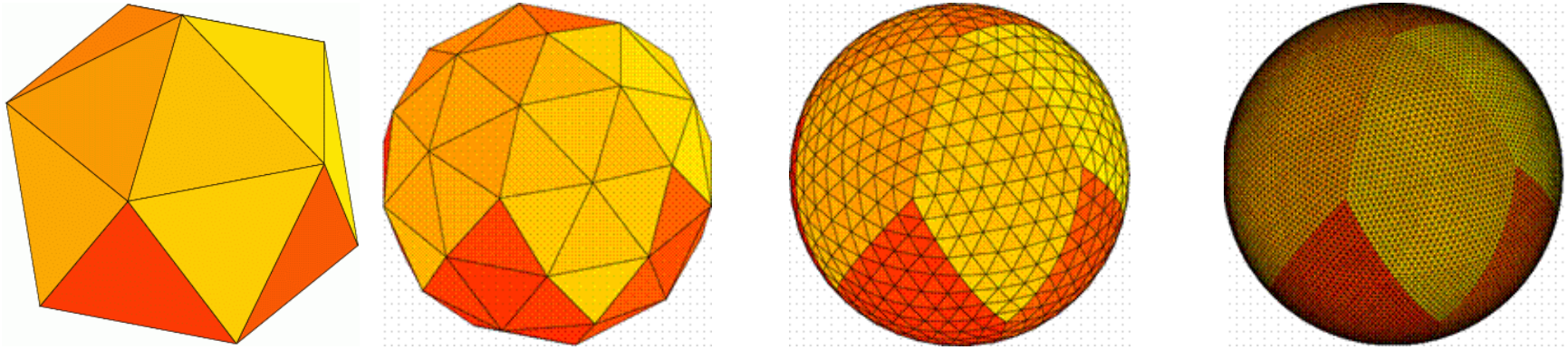
Yamasaki (2017)

First global cloud-resolving model

Break through

- The first global cloud-resolving model, NICAM, has been developed at JAMSTEC and University of Tokyo.
- Using NICAM and the super computer, a global cloud-resolving simulation without cumulus parameterizations reasonably simulated MJO event.

NICAM Icosahedral Grid



Tomita and Satoh (2004), Satoh et al.(2014)

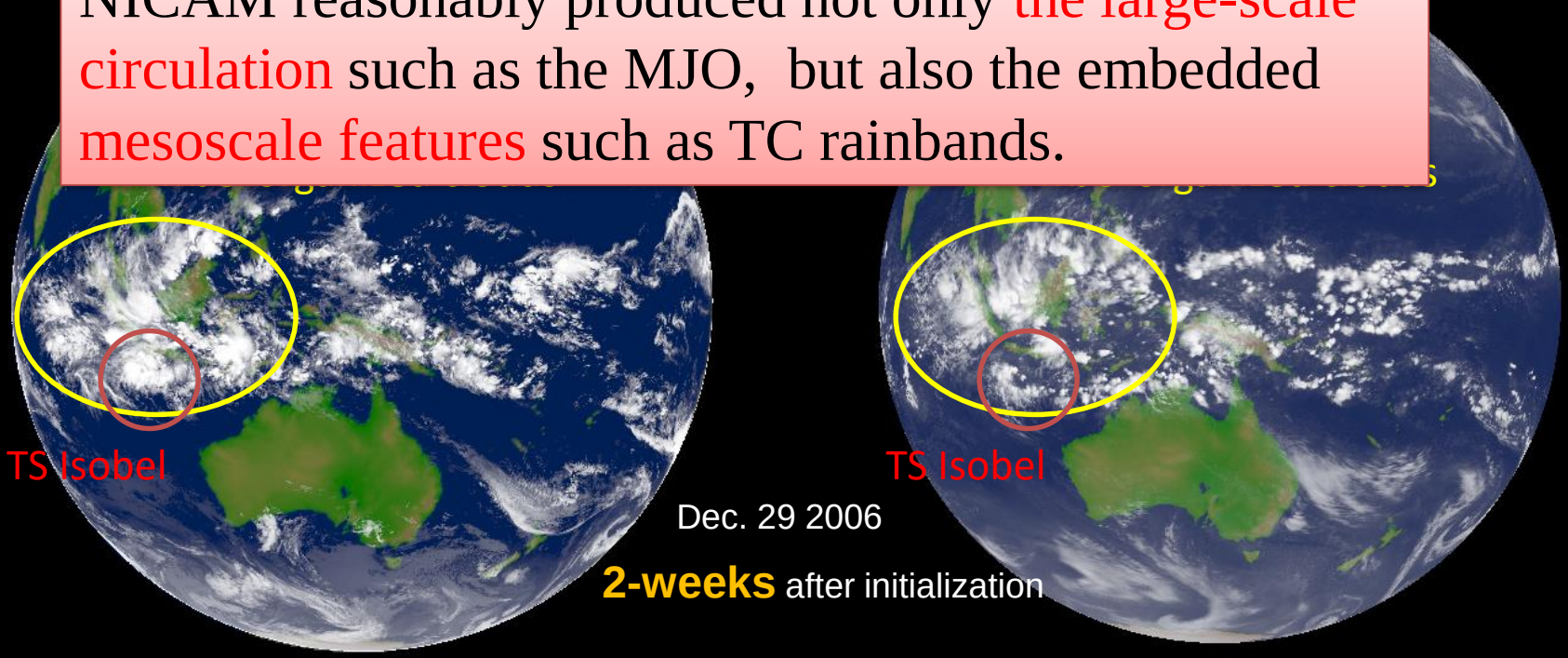
Observation vs. NICAM

MTSAT-1R

NICAM

x=7km

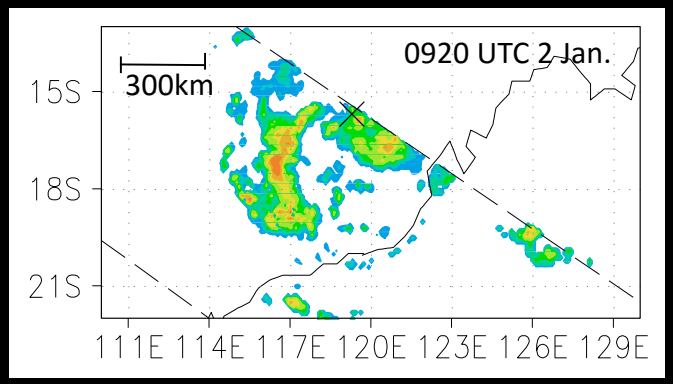
NICAM reasonably produced not only the large-scale circulation such as the MJO, but also the embedded mesoscale features such as TC rainbands.



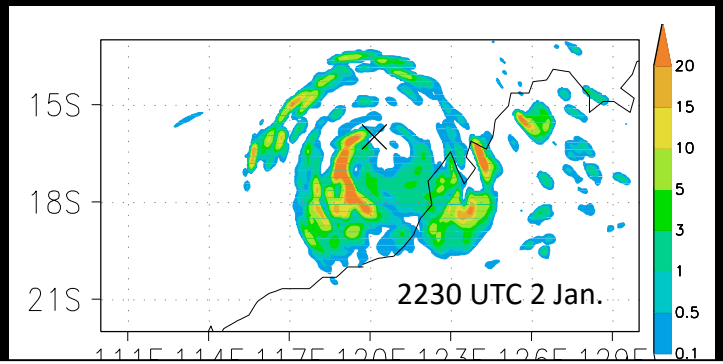
Dec. 29 2006

2-weeks after initialization

Surface rain rate (mm hour^{-1}) by TRMM-TMI



Surface rain rate (mm hour^{-1}) by NICAM

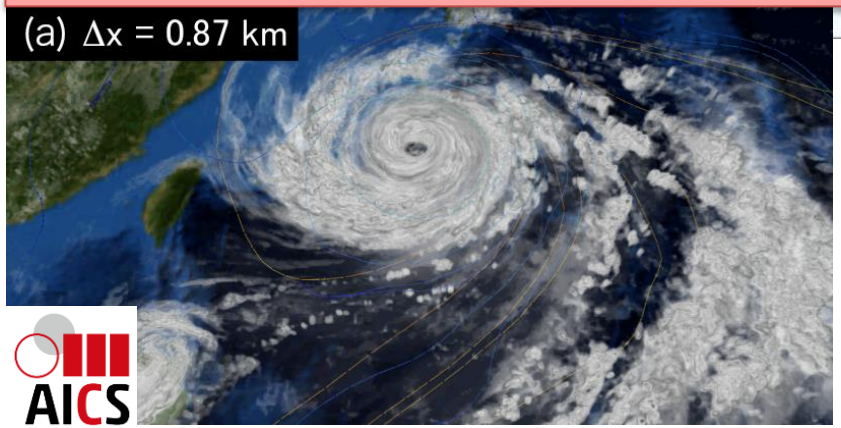


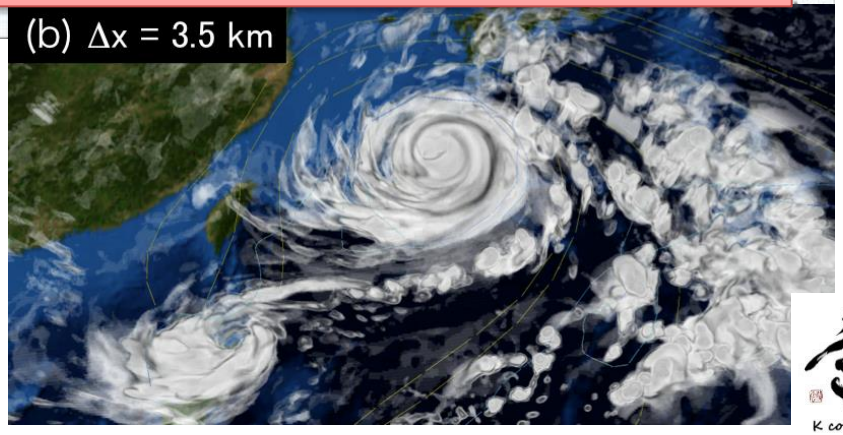
Miura et al. (2007) Fudeyasu et al. (2010)

Global 870m simulation

Miyamoto et al. (2013)

The **870 m global simulation** with world's highest resolution realistically simulated TCs.





RIKEN AICS K computer

7-km Global models intercomparison

The nonhydrostatic global spectral atmospheric Model using a Double Fourier Series developed by JMA

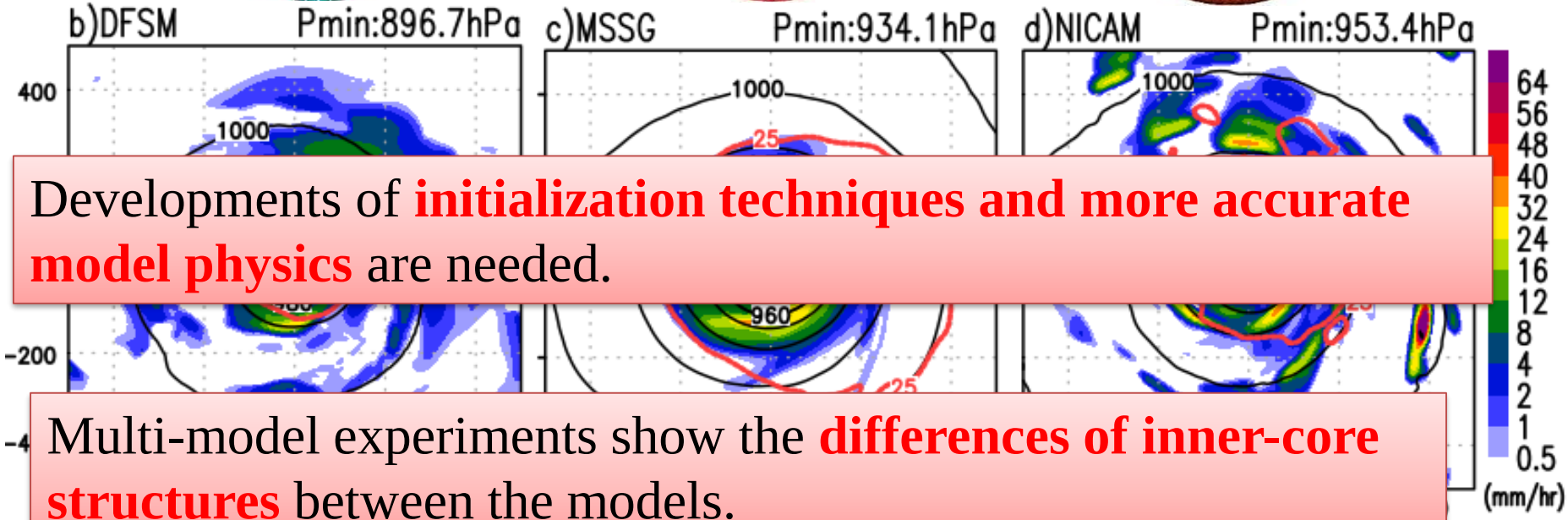
the Multi-Scale Simulator for the Geoenvironment developed by JAMSTEC.

DFSM

MSSG

NICAM

7km-GCMs can reasonably simulate TC track and axisymmetric structurer.



Developments of **initialization techniques and more accurate model physics** are needed.

Multi-model experiments show the **differences of inner-core structures** between the models.

Nakano et al. (2017)

Summary

Recent advances in computer power have made it possible to conduct **high-resolution TC simulations** with **numerical models developed in Japan.**

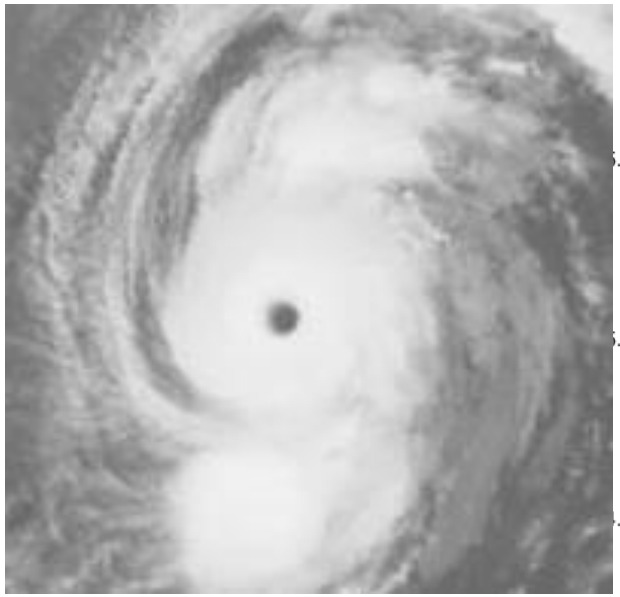
The **several/sub-kilometer regional-models simulation** contributed to our understanding on the TC lifecycle.

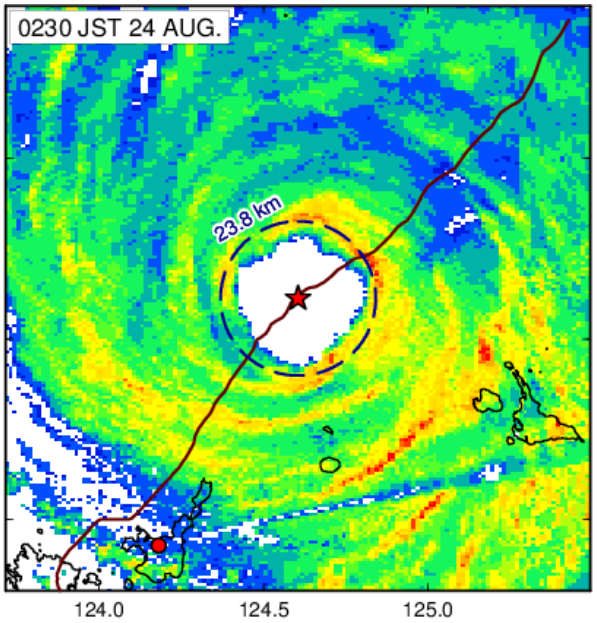
The **cloud-resolving global-models simulation** realistically reproduced the TC lifecycle.

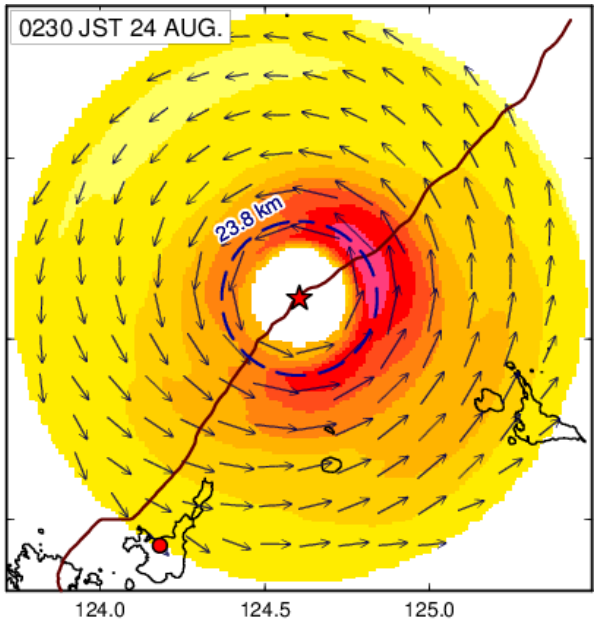
Developments of initialization techniques and more accurate model physics are needed to improve the TC prediction.

A mark of **new era for TC predictions** with **typhoon-resolving models** and **high-end powerful computers**.

Overview of Observational Studies of Tropical Cyclones in Japan



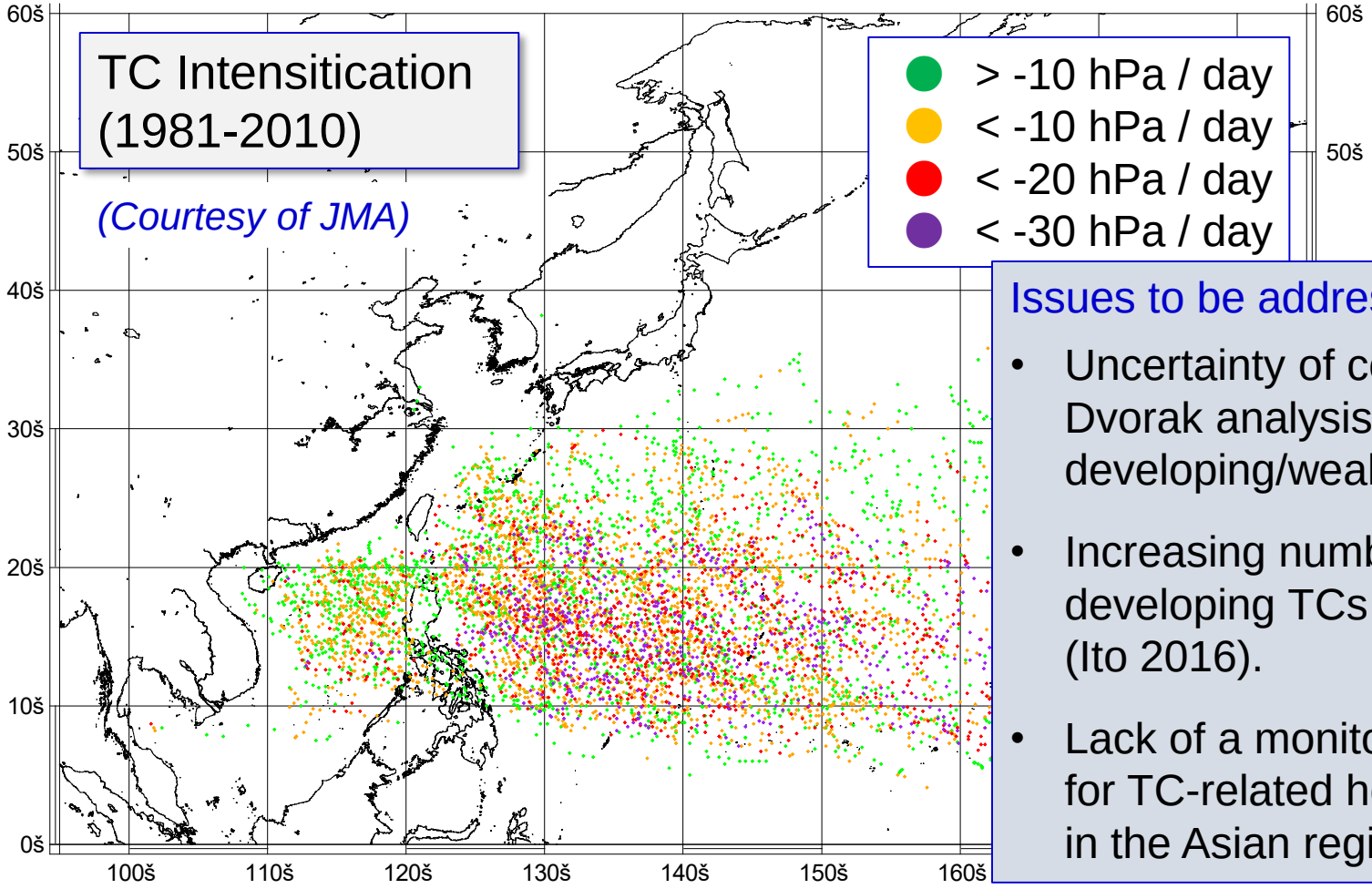




Hiroyuki Yamada
(University of the Ryukyus, Japan)

With Thanks to
U. Shimada, R. Oyama, T. Adachi, M. Yamaguchi (MRI-JMA),
S. Nishimura, N. Koide, K. Nonaka, K. Bessho (JMA),
and K. Tsuboki (Nagoya University)

TC intensification over the Western North Pacific



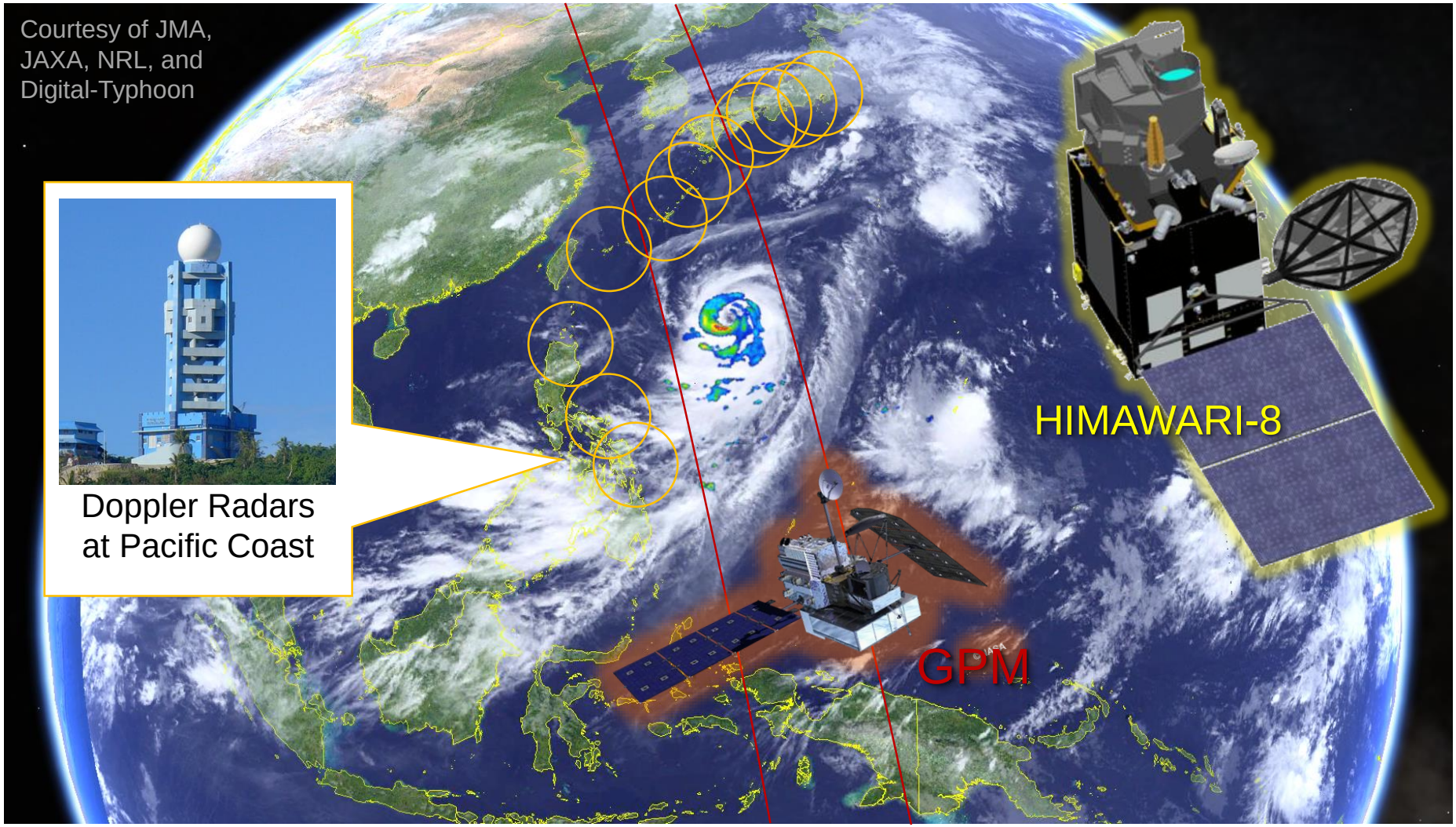
Issues to be addressed:

- Uncertainty of conventional Dvorak analysis for rapidly developing/weakening TCs.
- Increasing number of rapidly developing TCs in the WNP (Ito 2016).
- Lack of a monitoring system for TC-related heavy rainfall in the Asian region.

Goal of TC observational study:

- Accurate real-time monitoring of TC position, intensity, and related rainfall.
- Understanding of physical mechanisms govering TC intensification through tropical multi-scale processes, based on the “real” tropical atmosphere.

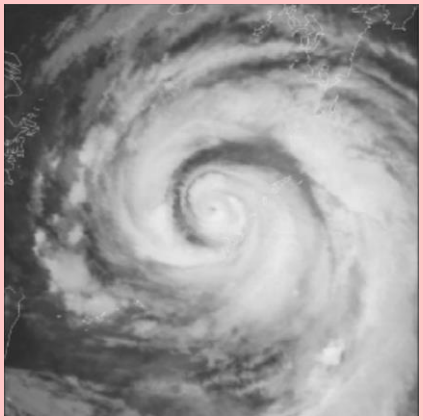
Recent Advances in TC Observation



Enhanced geostationary and microwave satellite observations, as well as increasing number of ground-based Doppler radars provide great possibility of improvement in both the monitoring and research of TC intensification.

Recent Advances in JMA's TC Monitoring System

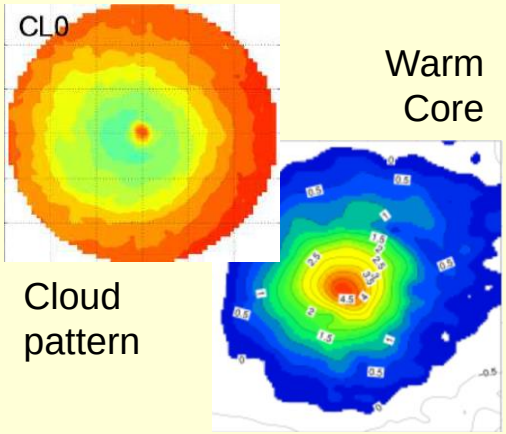
Conventional Dvorak



Objective Dvorak

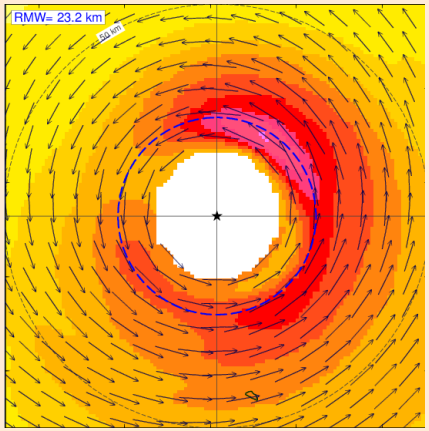
(Kishimoto et al. 2013)

(Under experiment)



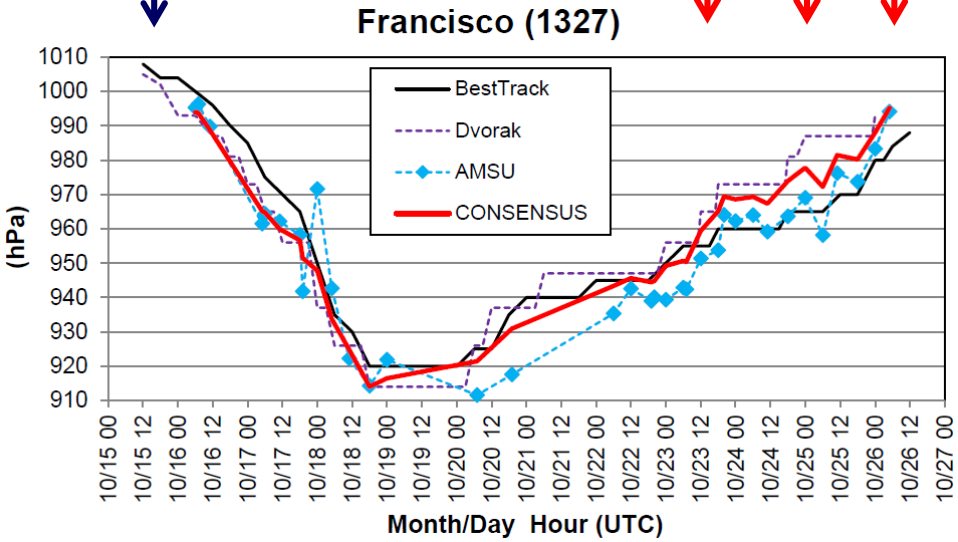
Microwave

(Sakuragi et al. 2016; Oyama et al. 2016)



Doppler Radar

(Shimada et al. 2016)

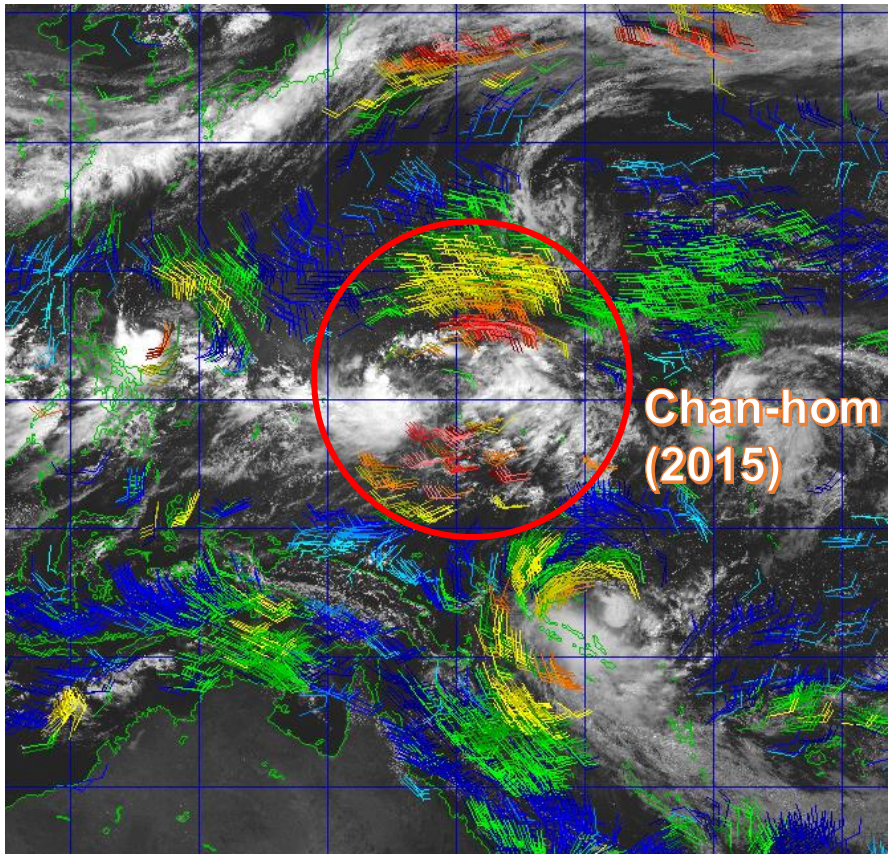


The reliability of intensity analysis can be enhanced by employing the consensus of independent objective techniques using geostationary and microwave satellites and Doppler radars.

Possibility of Rapid-Scan Atmospheric Motion Vector

Full Disk AMV

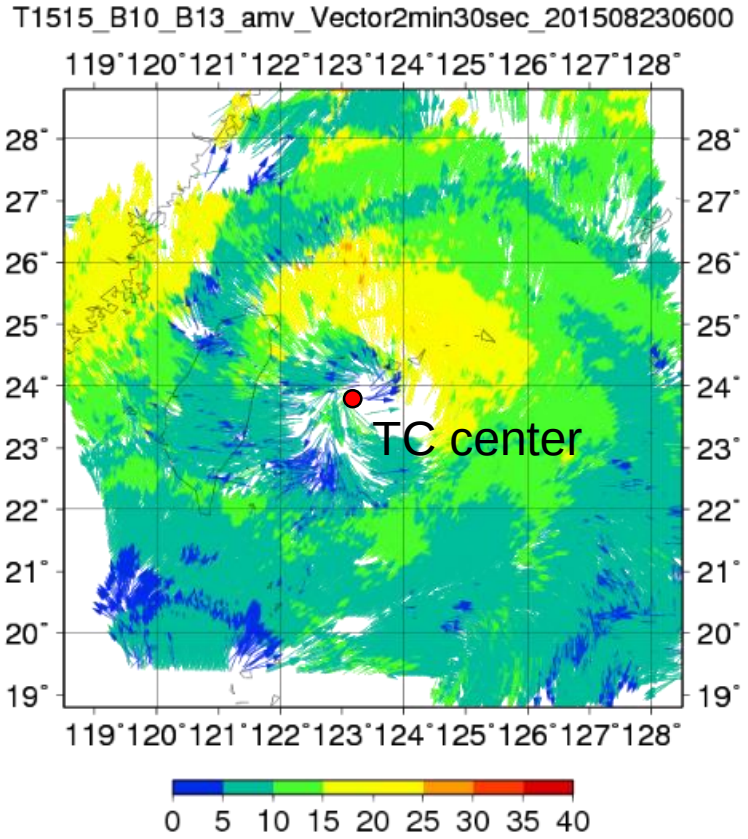
(Nonaka et al. 2016)



Potential for monitoring
TC environmental winds.

Rapid Scan AMV

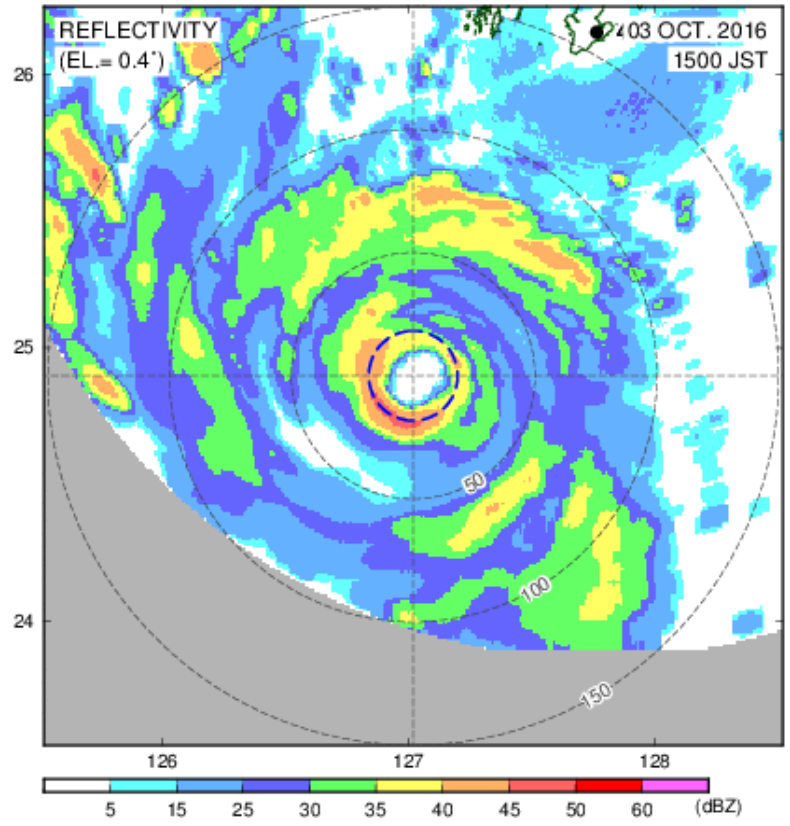
(Oyama et al. 2016)

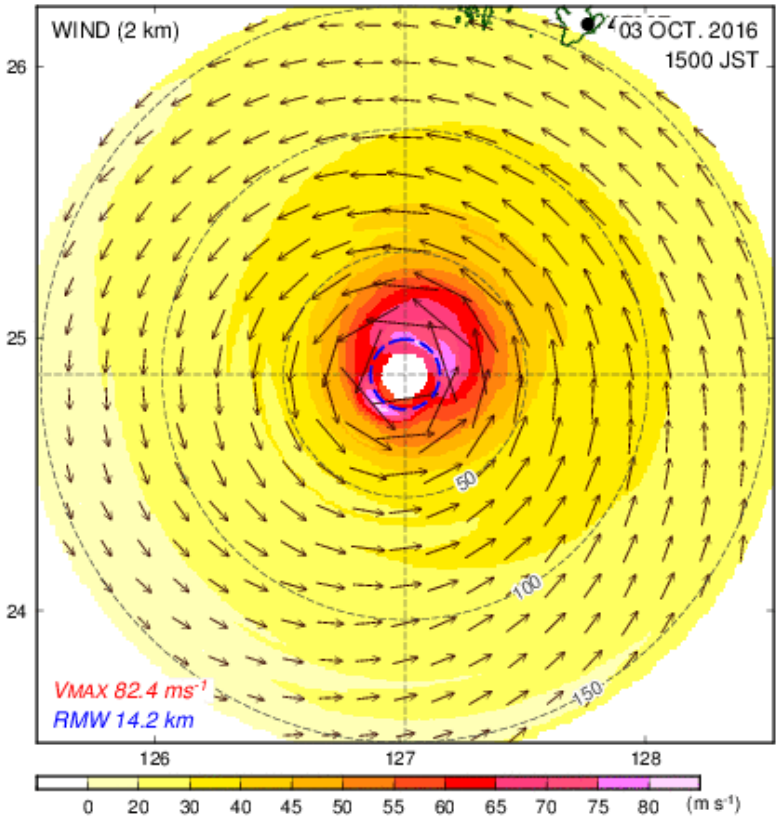


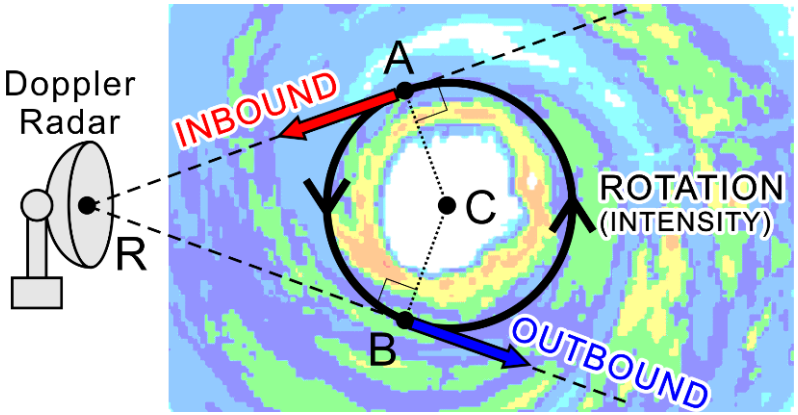
Potential for monitoring convective
blowout during rapid intensitication.

Under development for operational use in JMA.

Radar-Derived Intensity Estimation of Chaba (2016)



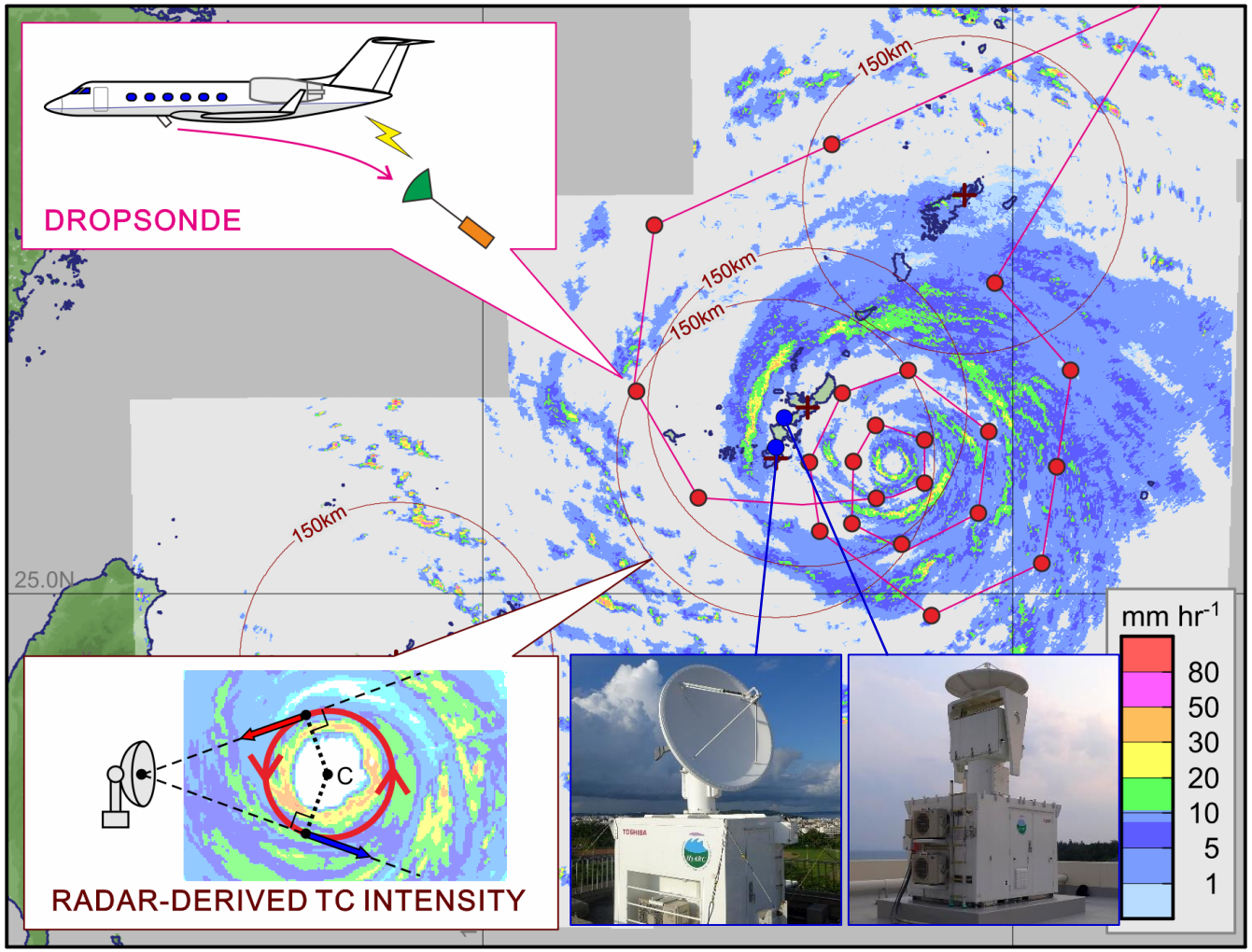




A compact structure with severe winds (> 80 m/s) and minimum pressure of ~905 hPa was successively monitored every 5 minutes using JMA Okinawa radar and Ground-Based Velocity Track Display (GBVTD) method.

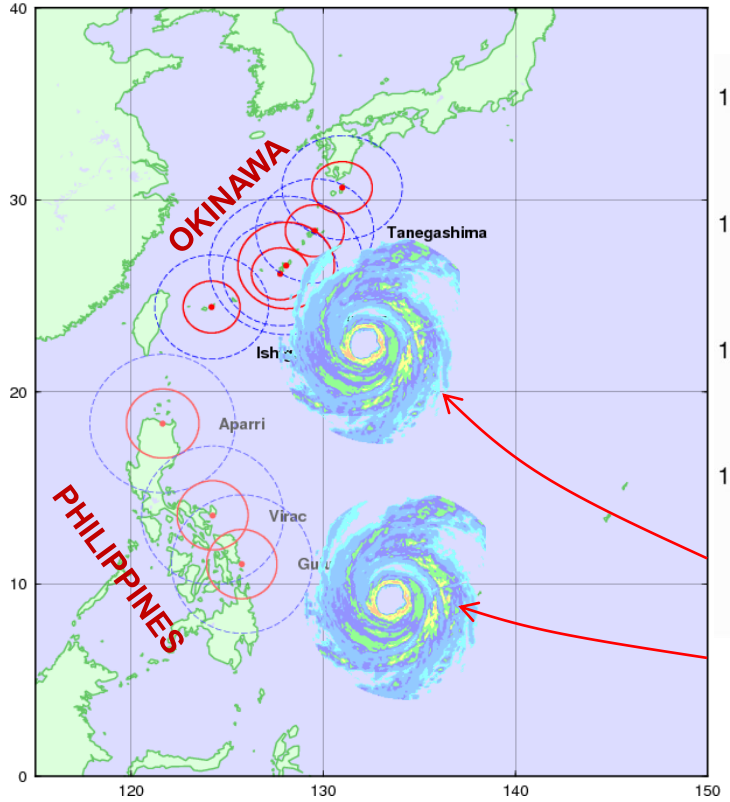
Field Experiment of TC Intensity and Structure in Okinawa

(by Nagoya University, University of the Ryukyus, and MRI-JMA)

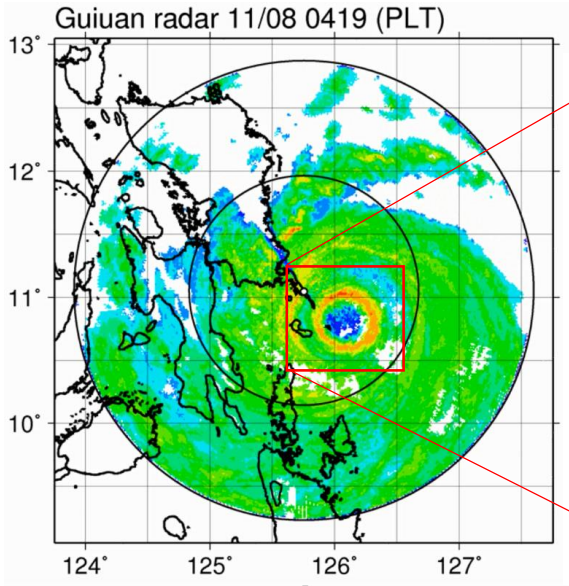


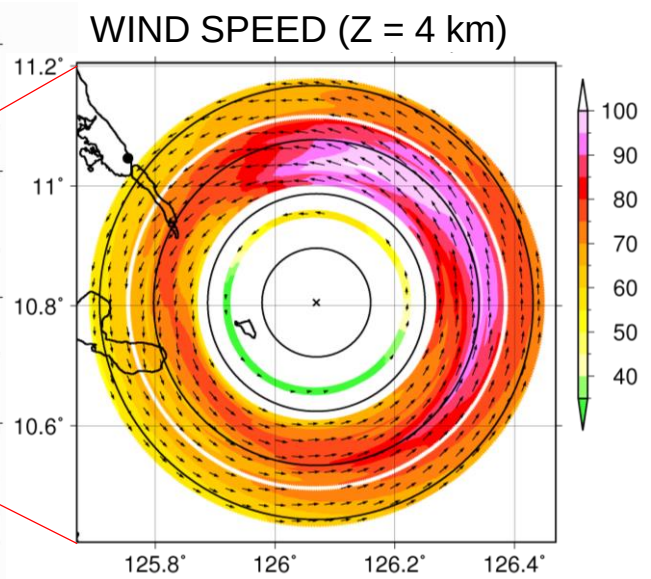
A grant-in-aid program of TC dropsonde and radar observations is carried out in the Okinawa area between 2017 and 2020.

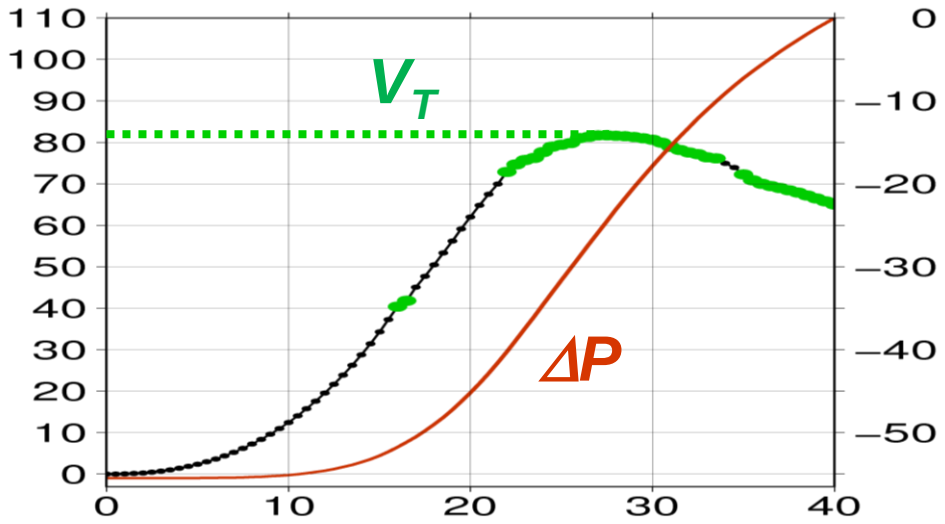
Cooperative Study on TC Intensity Estimation at Okinawa and Philippines



Shimada et al. (2017, to be submitted)



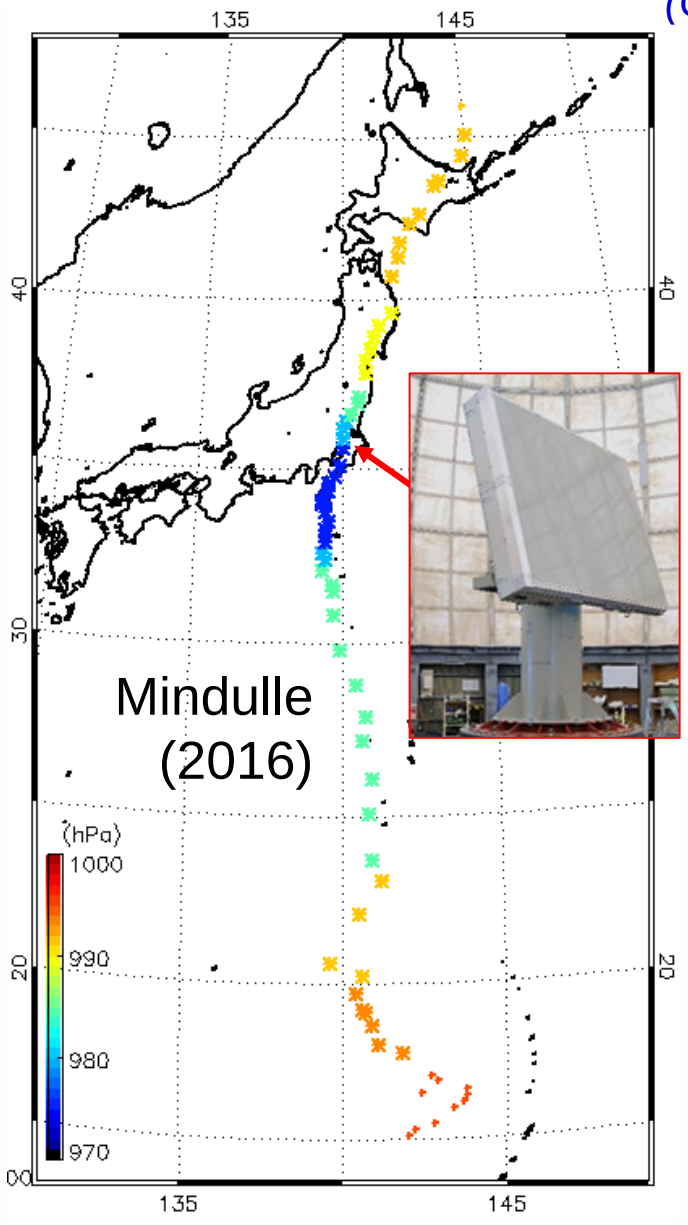


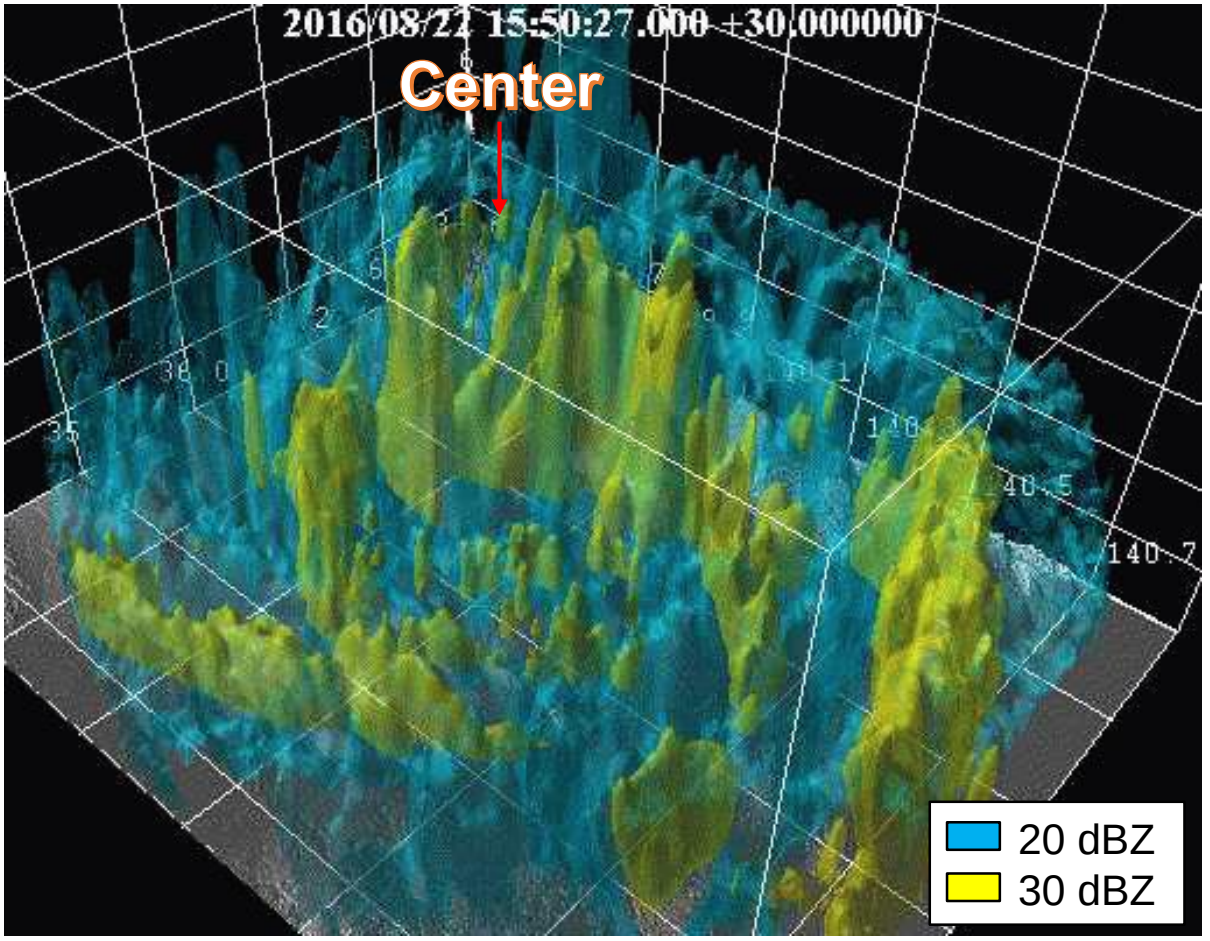


Intensity estimation of TC using PAGASA Doppler radars has been started since 2016. Intensity estimation of Typhoon Haiyan (2013) was conducted.

Observing the Center of Mindulle (2016) by a Phased-Array Radar

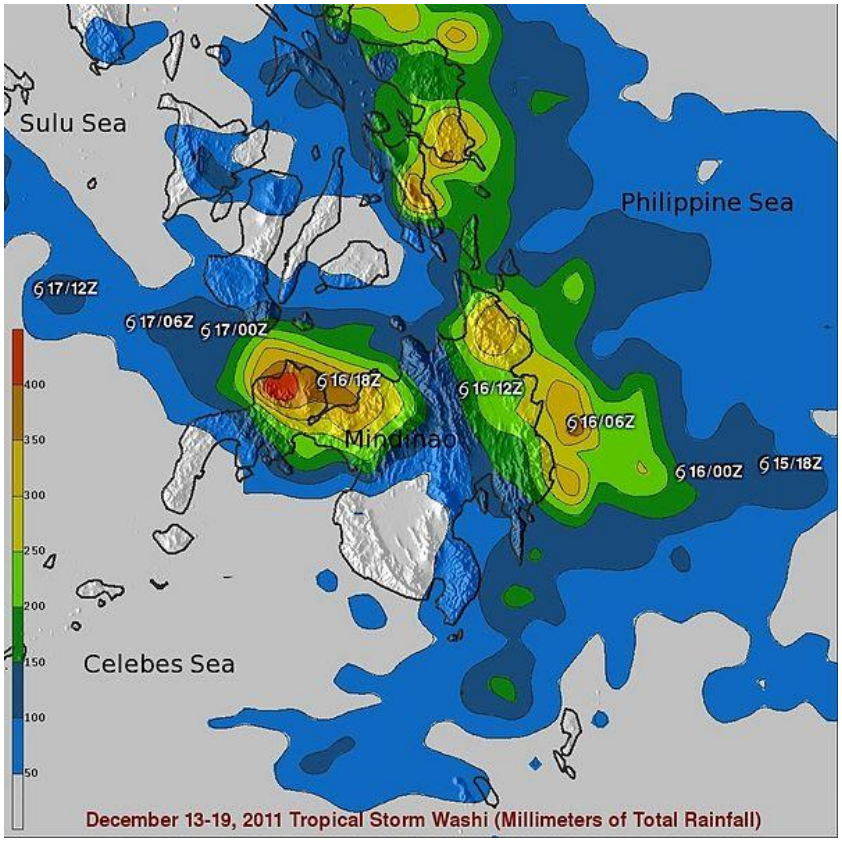
(Courtesy of Adachi, MRI-JMA)

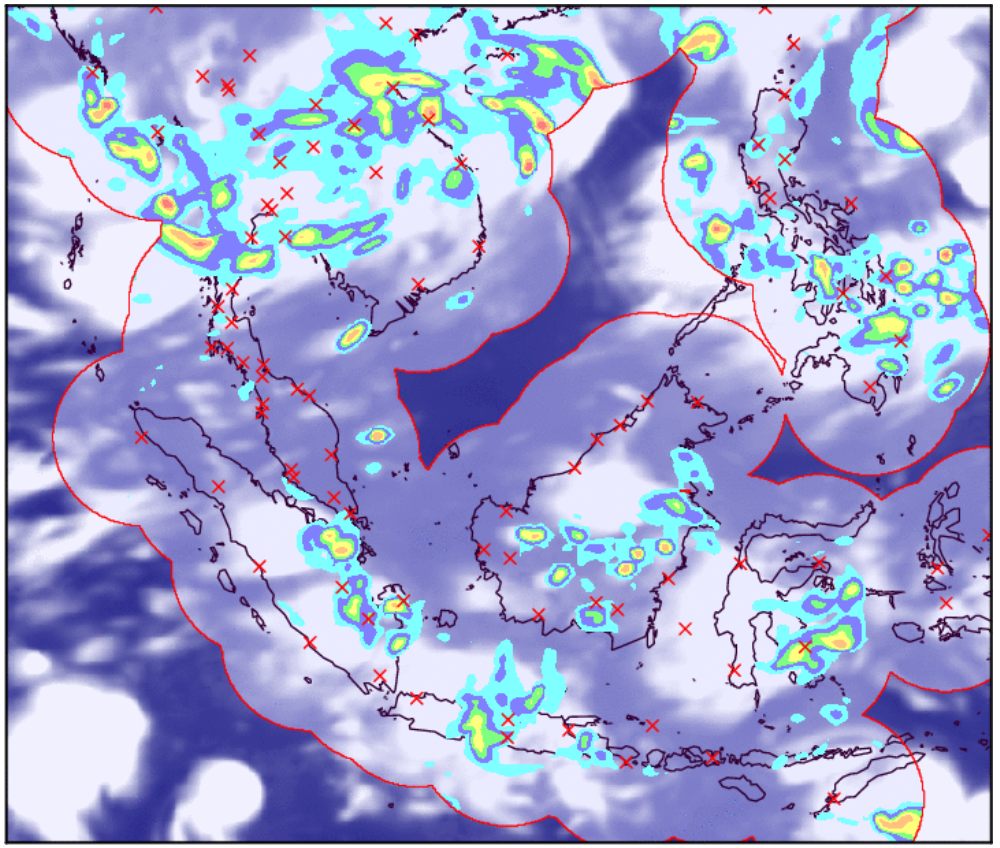




Succeeded in capturing changes in the structure of the typhoon by very frequent volume scan (every 30 seconds) by a phased array radar.

Potential of Ground-Based Radars for Quantitative Estimation of Typhoon-Related Heavy Rainfall





Heavy rainfall can occur not only with intense TCs but weak ones, such as TS Washi (2011).

Operational TC analysis does not cover rainfall distribution.

International “radar mosaic” within the Asian countries will contribute to not only real-time QPE but also further understanding of TCs in relation to tropical atmospheric motion.

Summary

- The reliability of real-time intensity analysis can be enhanced by employing the consensus of independent objective techniques using geostationary and microwave satellites and Doppler radars.
- More direct measurement of TC winds using high-frequent Himawari-8 images and ground-based Doppler radars can provide more accurate intensity estimation.
- Doppler radar observation and aircraft dropsonde observation can contribute to our further understanding of physical mechanisms governing TC intensification.

Future Directions

- Use of Himawari-8 AMVs and Doppler radars for operational analysis.
- Continuation of field experiments using radars and aircrafts.
- Collaboration among the Asian countries for radar synthesis for further understanding of TCs and their relationship to tropical meteorology.