Advanced Technology for Tropical Cyclone Observation, Analysis and Forecast in JMA

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TC50 TECO, Hanoi, Vietnam, 26 February 2018

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1. Introduction

Disasters caused by tropical cyclones (TCs)

Impact-based forecasts and risk-based warnings

- Real-time landslide risk map
- Real-time inundation risk map
- Real-time flood risk map
- High-resolution precipitation nowcasts

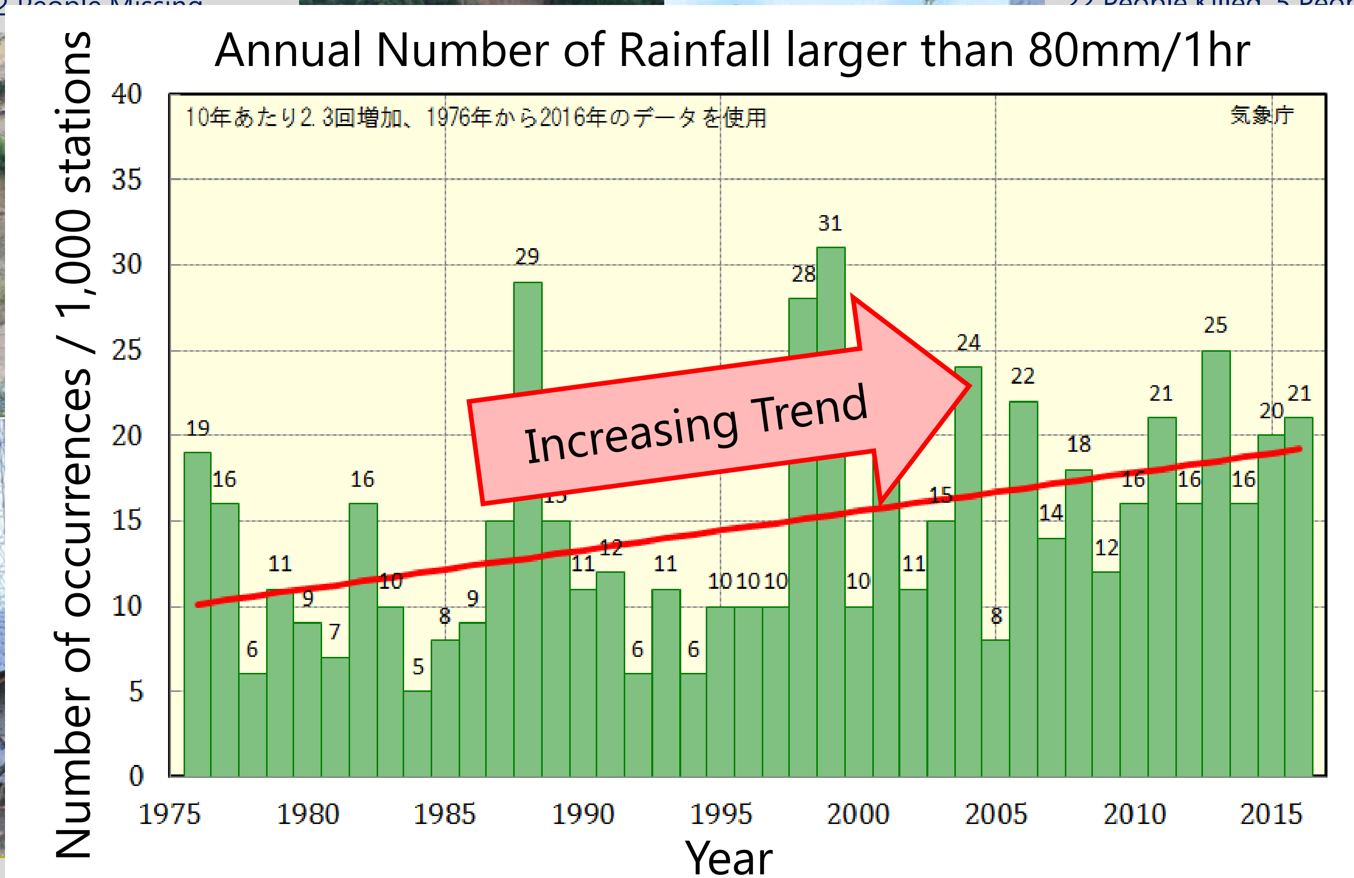
Recent TC-related Disasters in Japan

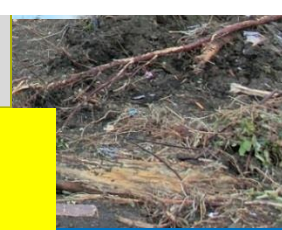
Flood & Landslide Disaster by Nanmadol (T1703)

5 Jul. 2017
545.5 mm/24hr in Asakura, Fukuoka
42 People Killed, 2 People Missing

Flood Disaster by Lionrock (T1610)

30 Aug. 2016
231 mm/24hr in Kuji, Iwate
22 People Killed, 5 People Missing





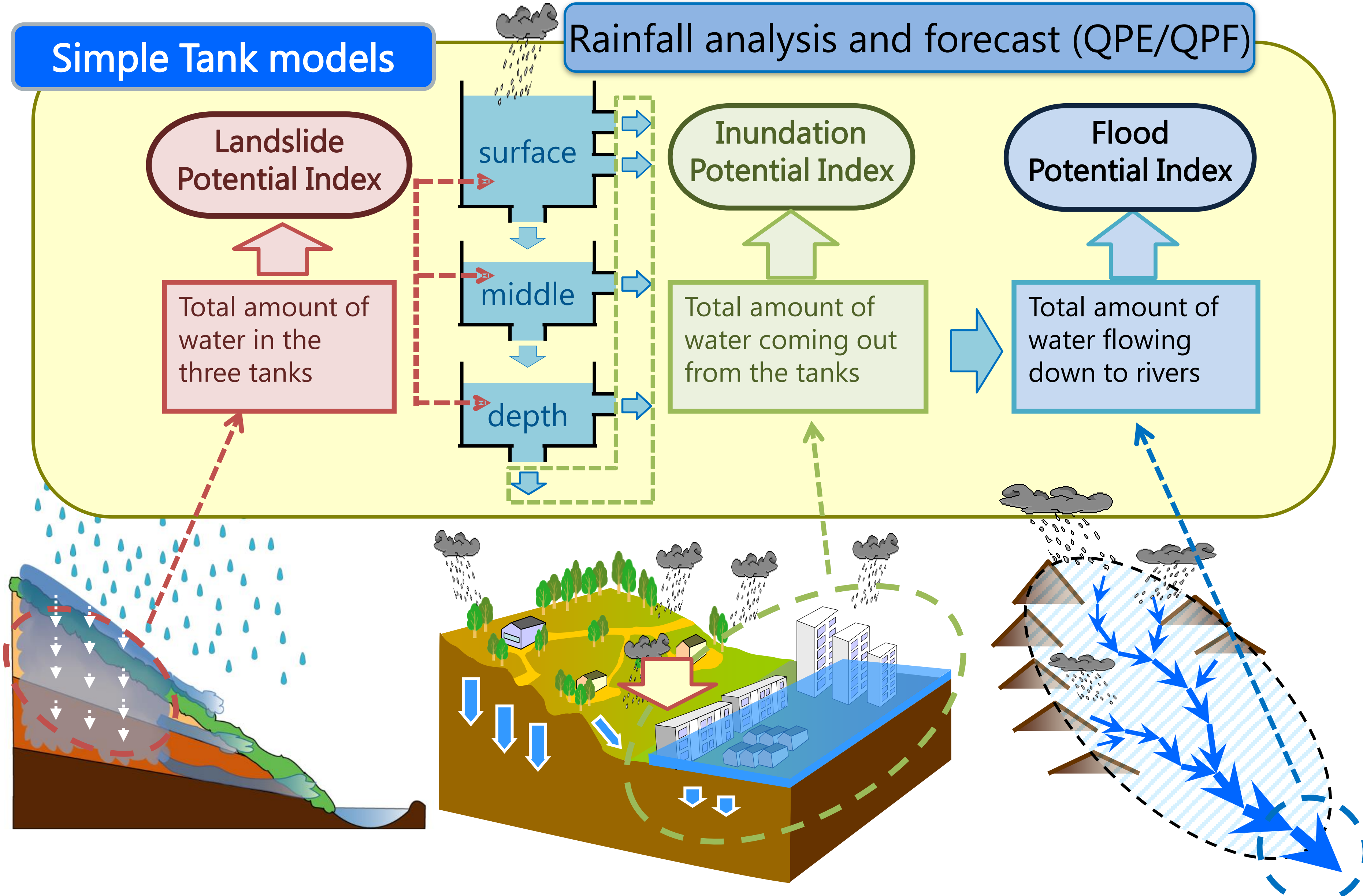
16 Oct. 2013
122.5mm/1hr, 824.0mm/24hr in Izu-Oshima
35 People Killed, 4 People Missing

Landslide Disaster by Wipha (T1326)

7 - 10 Sep. 2015
541.0mm/24hr in Imaichi, Tochigi
7,280/12,035 houses flooded above/below floor level

Flood Disaster by Kilo (T1517) & Etau (T1518)

Hazard Potential Indices



Utilization of Real-time Potential Risk Map

Warning Message

- Heavy rain Advisory
- Heavy rain Warning
- Landslide Disaster Alert Information
- etc.

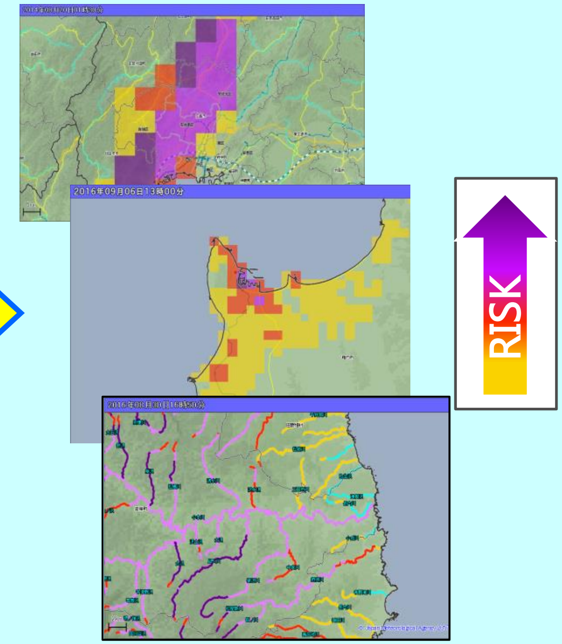
Inform Increase of Risk

Emergency managers

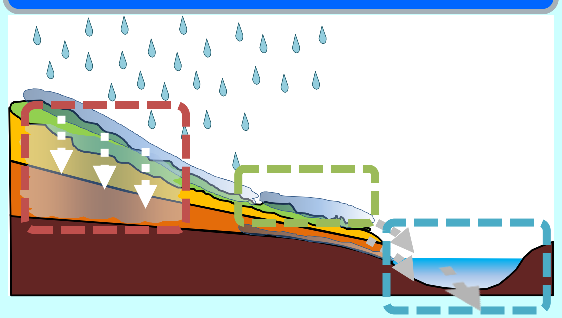
Residents

Check the risk area in detail

Potential Risk Map



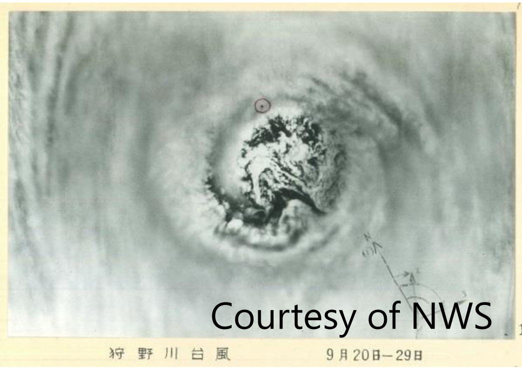
Hazard Potential Indices

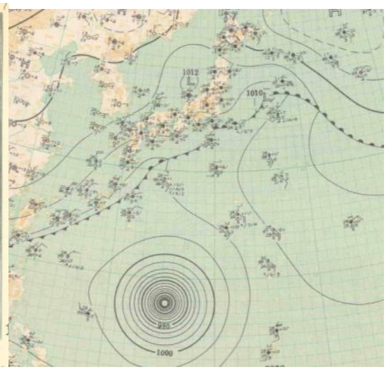


2. Observation and Monitoring

a. Satellite Observation (Himawari, etc.)
b. Ground-based Observation (Radar etc.)

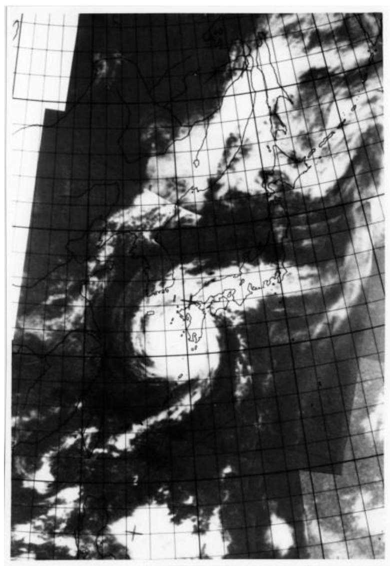
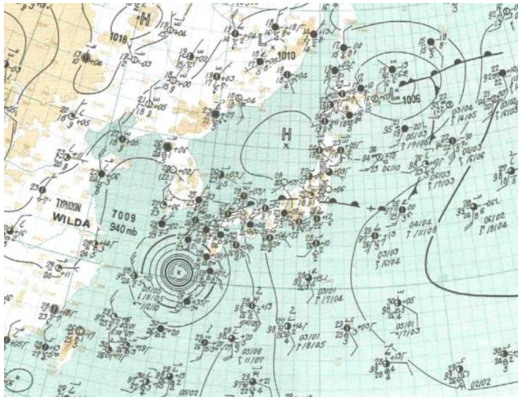
Observation from Aircrafts and Satellites





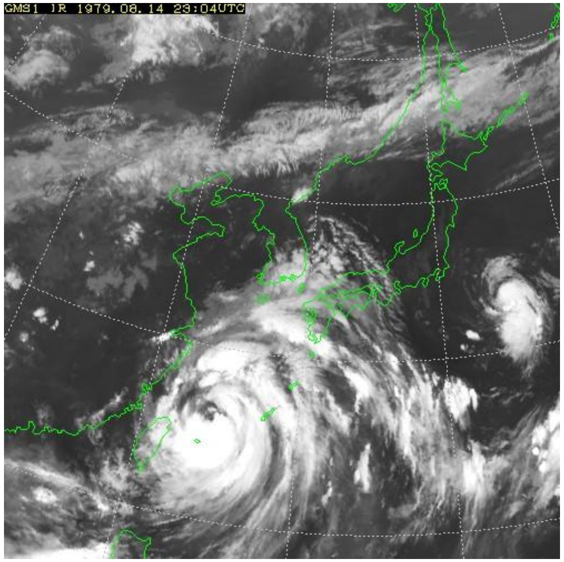
Ida (T5822) on 24 Sep. 1958

- ✓ Aircraft reconnaissance of western Pacific typhoons was done by the U.S. military till 1987.

Wilda (T7009) on 14 Aug. 1970

- ✓ JMA has received images from Polar-orbiting satellites named ESSA twice a day since 1968.



Irving (T7910) on 14 Aug. 1979

- ✓ JMA launched GMS in 1978 and 3 hourly images became available.

History of Japanese Himawari Series

GMS (Geostationary Meteorological Satellite)

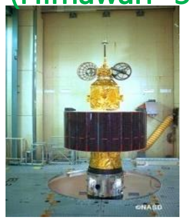
GMS (Himawari)

Jul 1977

GMS-2 (Himawari -2)

Aug 1981

GMS-3 (Himawari -3)



Aug 1984

GMS-4 (Himawari -4)

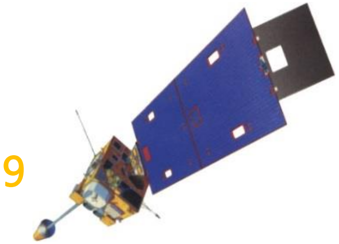
Sep 1989

GMS-5 (Himawari -5)

Mar 1995

3 hourly | hourly

GOES-9



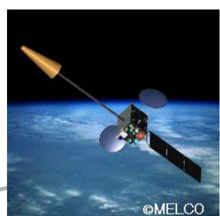
Back-up operation of GMS-5 with GOES-9 by NOAA/NESDIS
2003.5.22 – 2005.6.28

MTSAT (Multi-functional Transport SATellite)

MTSAT-1R (Himawari-6)

Feb 2005

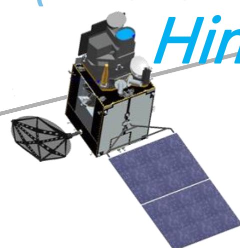
MTSAT-2 (Himawari-7)



Feb 2006

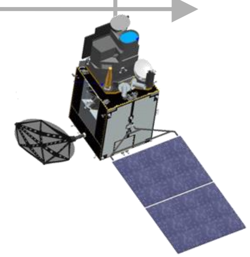
Himawari

(Himawari -8)



Oct 2014

(Himawari -9)



Nov 2016

half-hourly | every 10 min/ 2.5 min

Satellite	Observation period
GMS	1978 – 1981
GMS-2	1981 – 1984
GMS-3	1984 – 1989
GMS-4	1989 – 1995
GMS-5	1995 – 2003
GOES-9	2003 – 2005
MTSAT-1R	2005 – 2010
MTSAT-2	2010 – 2015
Himawari-8	2015 –
Himawari-9	2022–(Plan)

Imagery Products for Asia-Oceania Region

✓ Anyone can get these products by real-time JPEG imagery service through MSC website for Asia-Oceania region via the Internet.
http://ds.data.jma.go.jp/mscweb/data/himawari/index.html

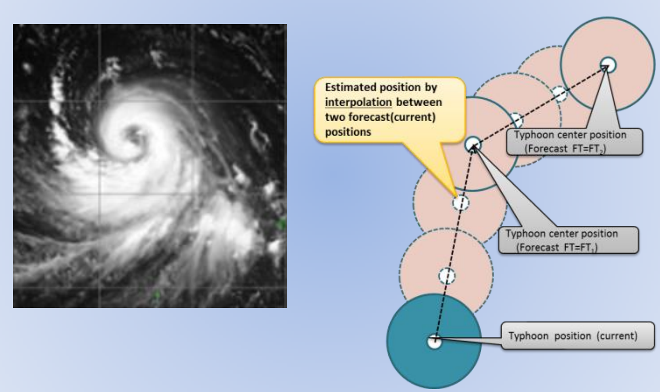
Providing imagery on MSC website

- Easy access to Himawari imagery
- **Processed into sectored images in JPEG format for**
  - Australia
  - Central Asia
  - Pacific Islands
  - Southeast Asia

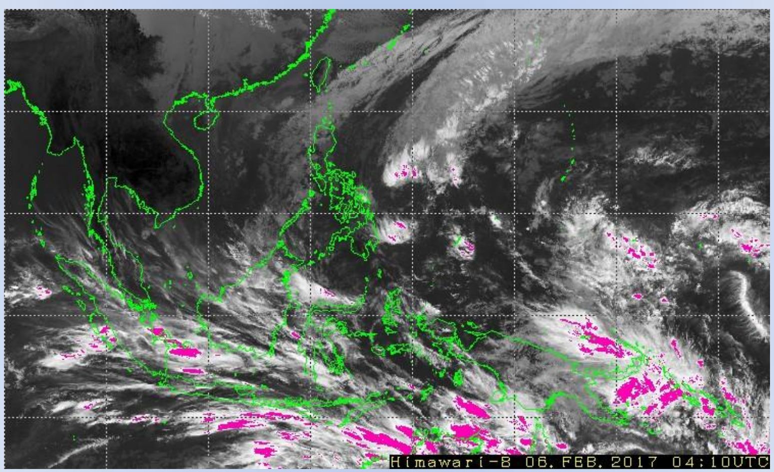
and more....

on real-time basis with animation in the last 23 hours

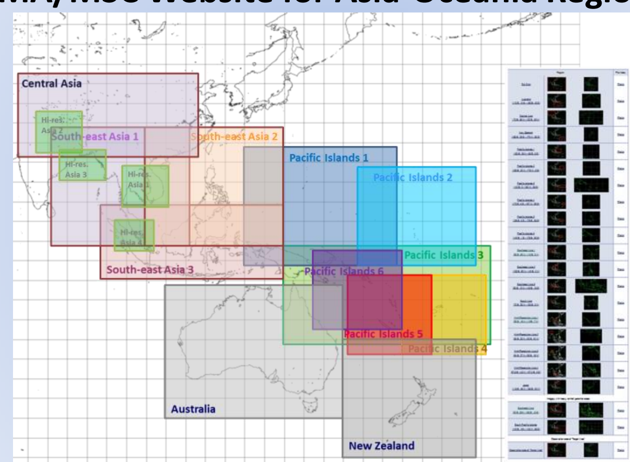
Target area observation



Imagery with heavy rainfall potential areas

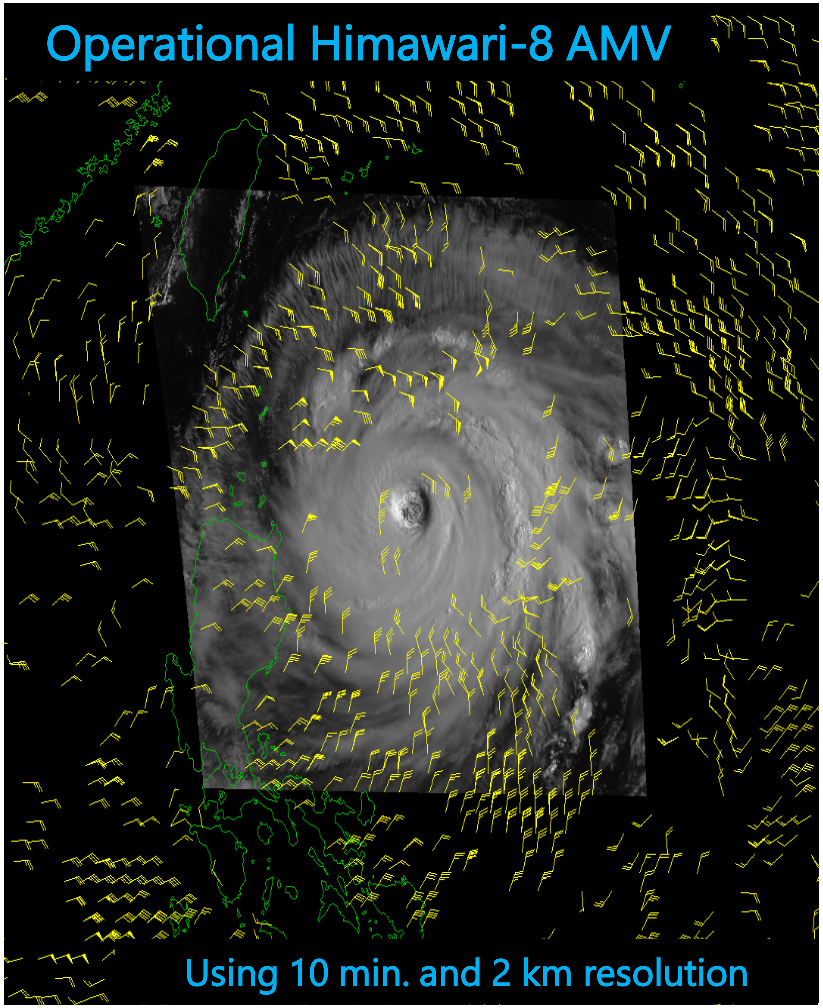


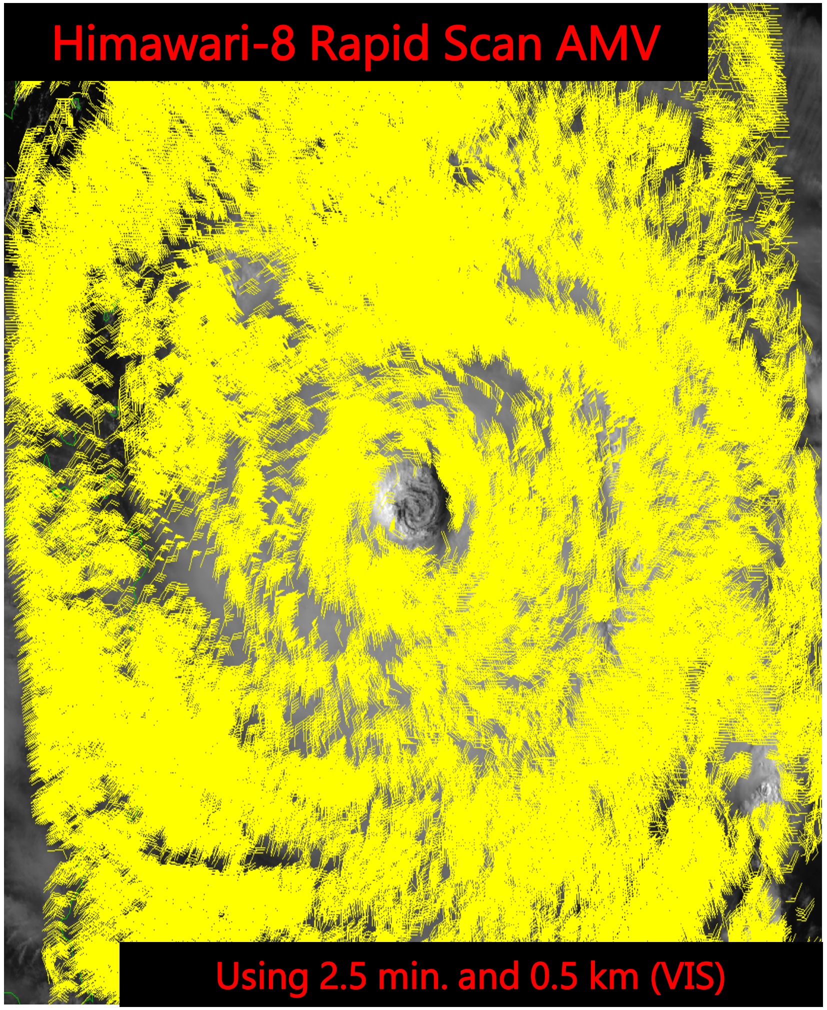
Real-time JPEG Imagery Service through JMA/MSC Website for Asia-Oceania Region



RS-AMV from AHI Target Observation

- ✓ Rapid scan AMV of Himawari-8 yields not only increase of temporal resolution but also increase of spatial resolution and data quality.

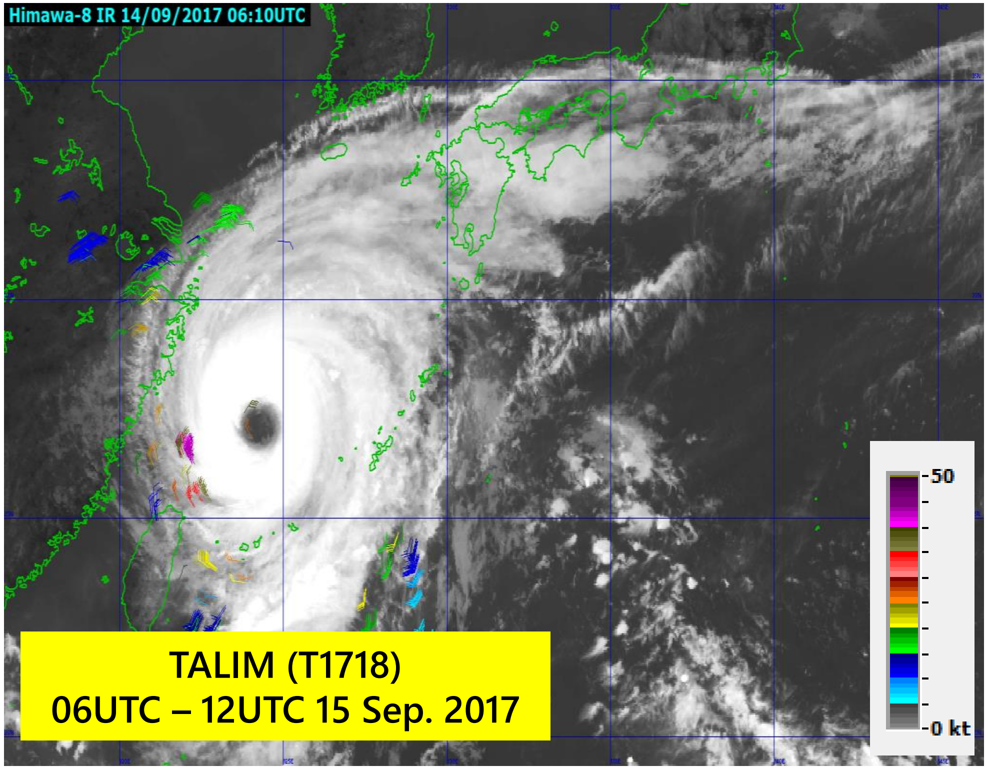




IR and VIS AMVs (QI>60, 00UTC August 20th 2015)

Himawari-8 RS-AMVs for Typhoons Analysis

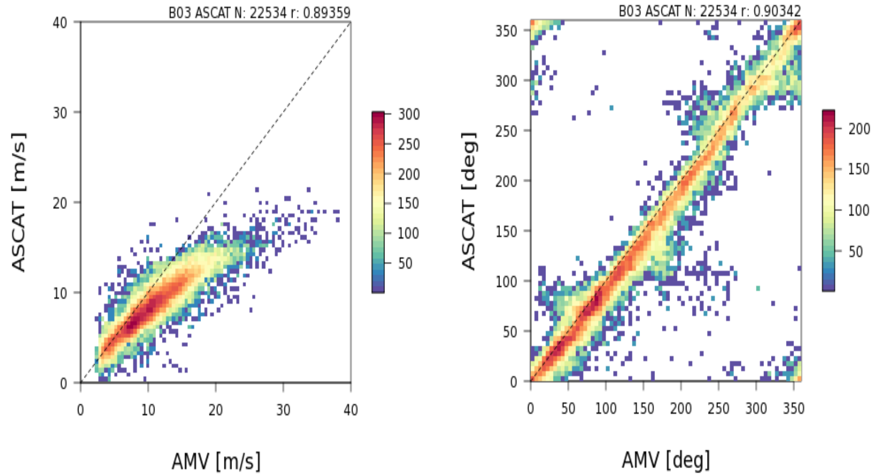
- ✓ Between low level AMVs and sea surface winds of ASCAT, they have good correlation around a typhoon.
- ✓ Sea surface winds estimated from low-level AMVs are provided to the Tokyo Typhoon Center to use for their operational typhoons analysis.



Estimated sea surface wind from the low-level RS-AMVs (IR and VIS) that are calculated every 10min using 5/2.5min images. (Background is full disk IR image)

Low-level AMV vs ASCAT

Wind Speed | **Wind Direction**



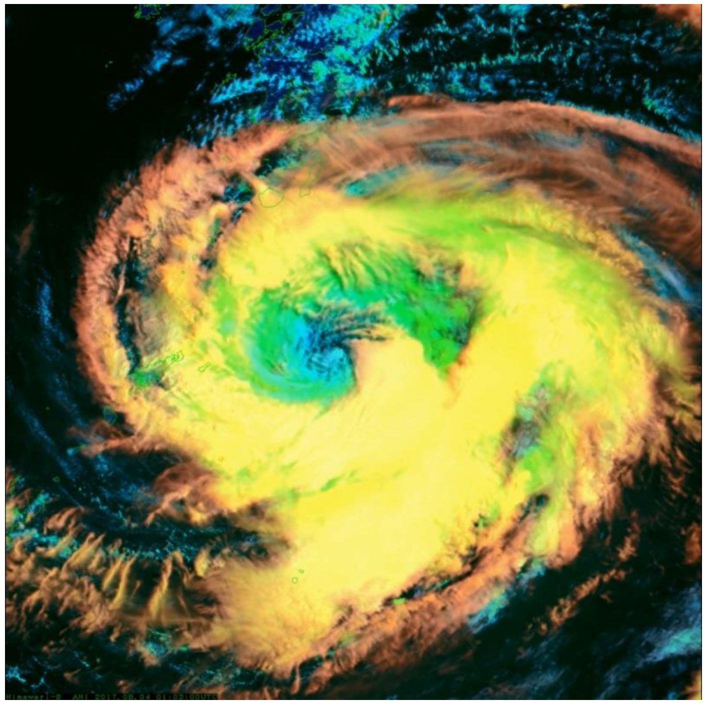
Low level AMVs (AMV height ≥ 700hPa , QI(w/o forecast) ≥ 0.8)

To estimate ocean wind speed by low-level AMVs around a typhoon using linear regression -> monitor typhoons

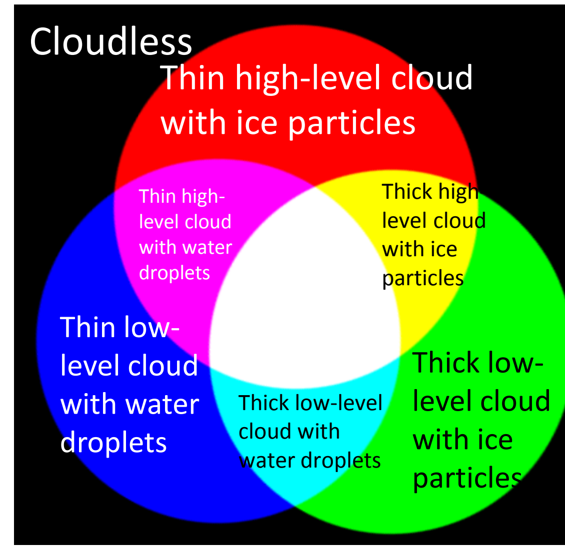
Himawari-8 RGB Image for Typhoons Analysis

✓ TC related very active convective clouds with heavy rain and cloud types can be visually monitored by using RGB images in real time base

Application:
Analysis cloud thickness, height of cloud top and cloud phase at one time.



Typhoon Noru (T1705)



Interpretation (under investigation)

R	B13(IR 10.4)	1.0	219.62～280.67[K]
G	B03(VS 0.64)	1.0	0.00～0.78
B	B05(N2 1.6)	1.0	0.01～0.59

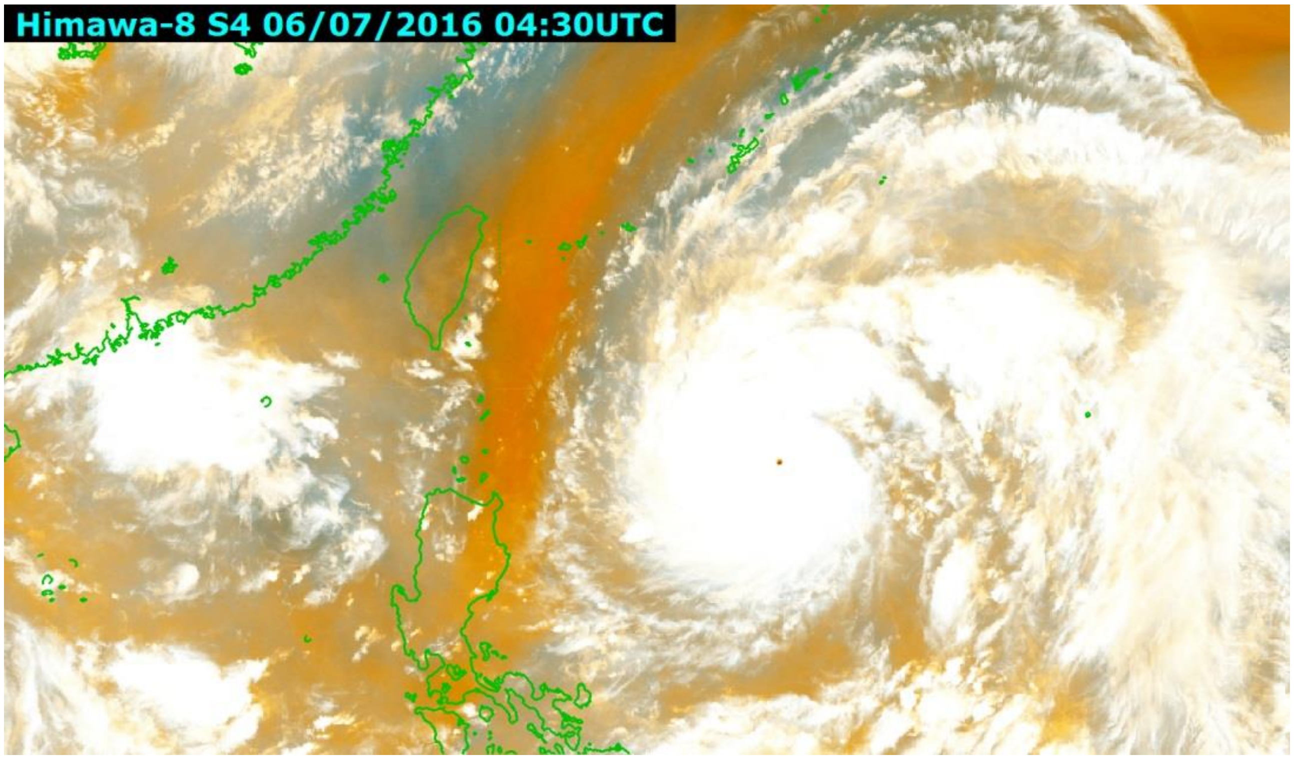
→ Cloud height

→ Cloud thickness

→ Cloud phase

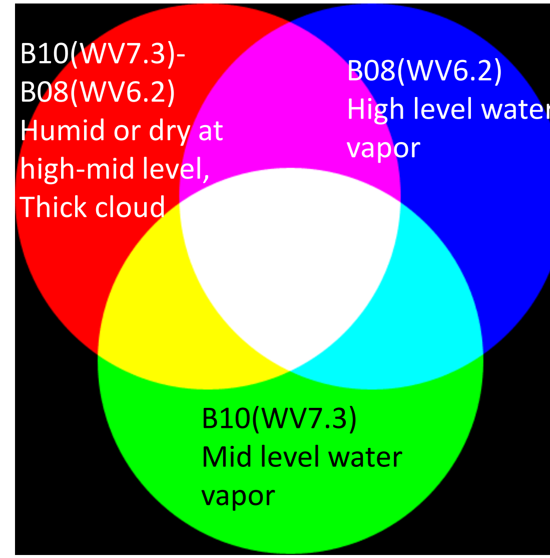
Water Vapor Monitoring with Himawari RGB Image

✓ Water vapor distribution affecting intensity of TCs is also monitored by a kind of RGB images.



Water Vapor RGB

04:30UTC July 6, 2017 Typhoon NEPARTAK (1601)



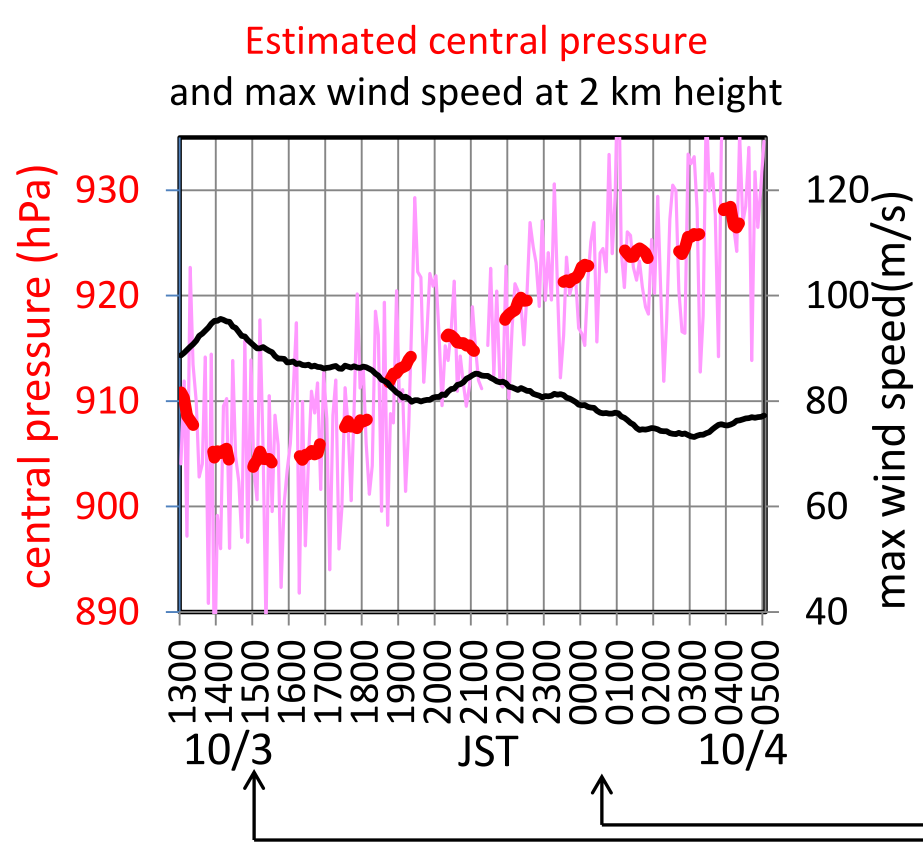
- Cloud with high level top
- High level: humid
- High level: dry / Mid level: humid
- High-mid level: dry

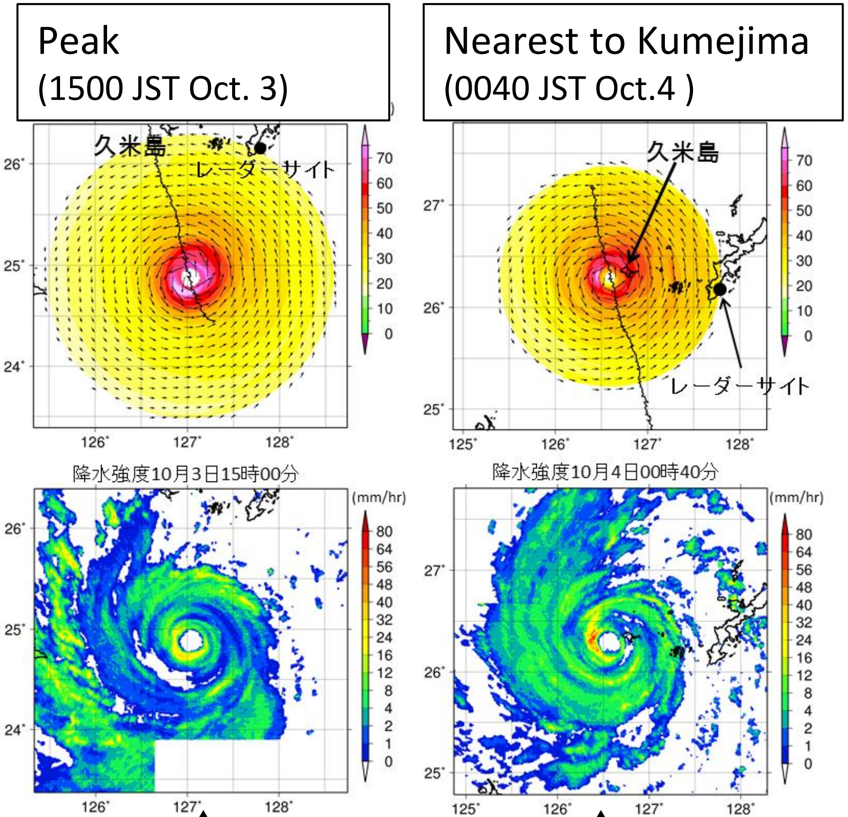
Mid level cloud

Interpretation
(under investigation)

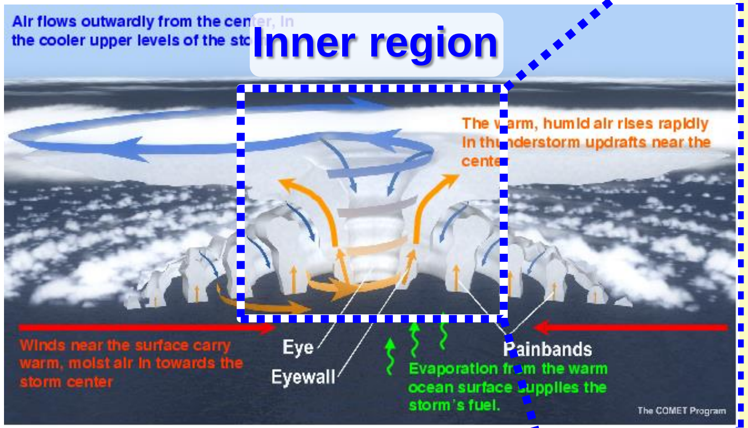
TC Intensity Analysis with Ground-based Radar

- ✓ It is estimated that the typhoon was in the south of Kumejima with the central pressure in the range of 900 hPa to 910 hPa for October 3, 18JST.
- ✓ At that time, the wind speed of 80 m / s or more was blowing at the altitude of 2 km near the center.
- ✓ The typhoon had a very compact and sharp structure, and the strongest wind was blowing on the left side of the route near the eye wall.

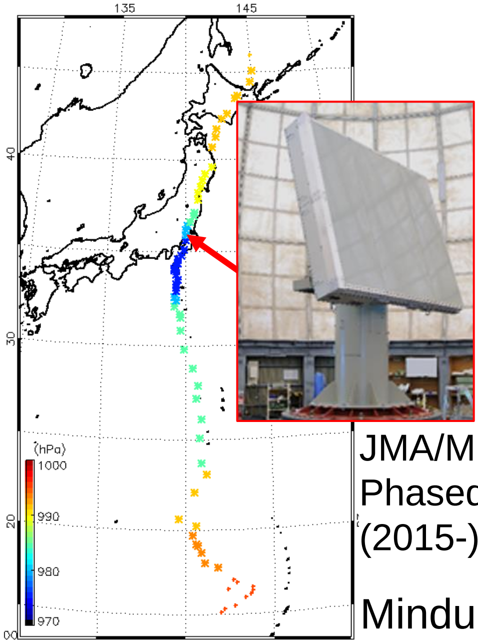




TC Structure Captured by a Phased Array Radar

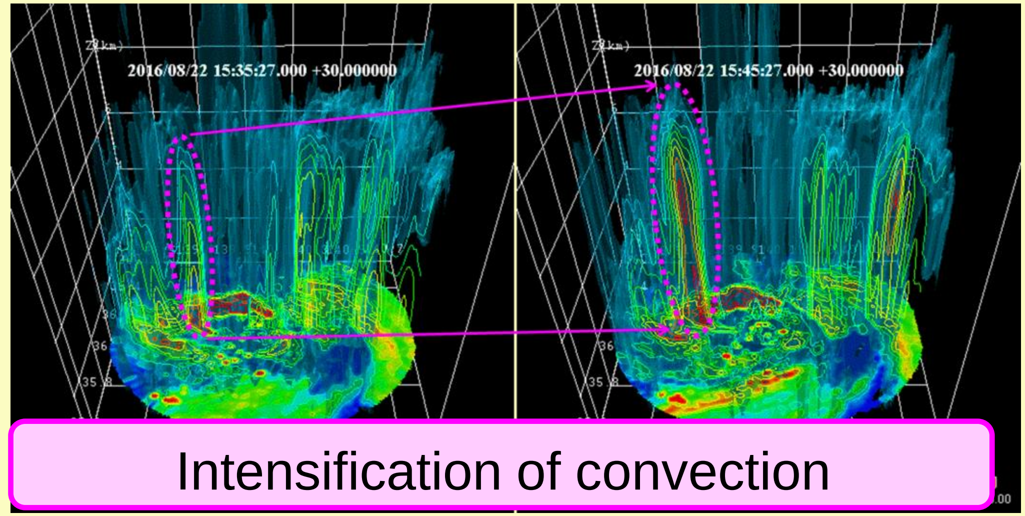


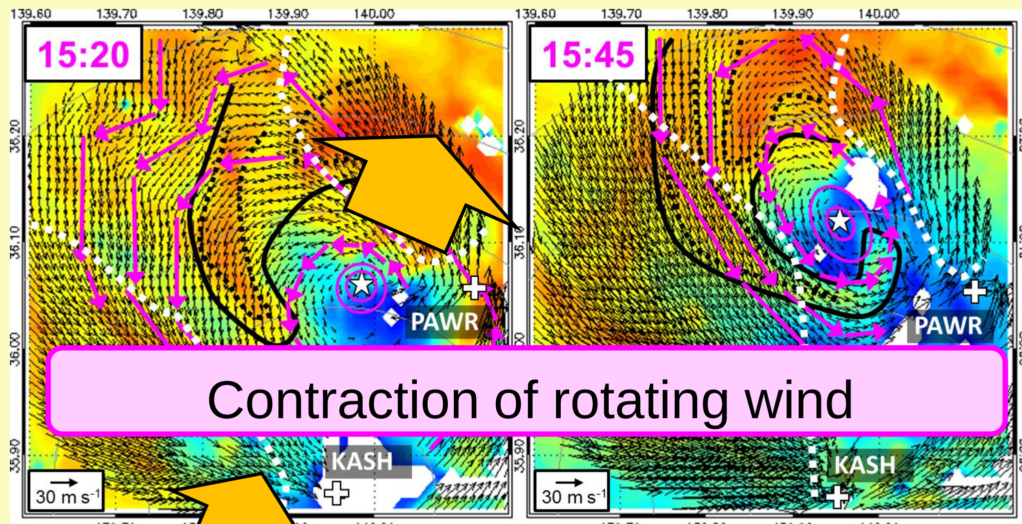
© NOAA Geophysical Fluid Dynamics Lab.



JMA/MRI X-band Phased- Array Radar (2015-)

Mindulle (T1609)





Landfall

Rapid change of 3D reflectivity and wind field structures

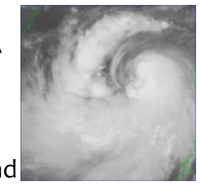
3. Analysis

TC Position & Intensity Analysis

Regular Observation and Analysis

History of TC Analysis

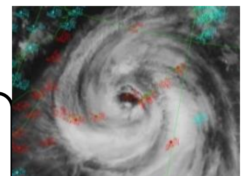
IR



IR,VIS and SYNOP, SHIP

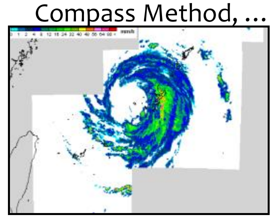
Gestational Satellite

Surface, Ship and Upper



Gestational Satellite, Surface, Ship and Upper data are essential for TC analysis when the TC is at sea area.

Dovorak Method, Compass Method, …



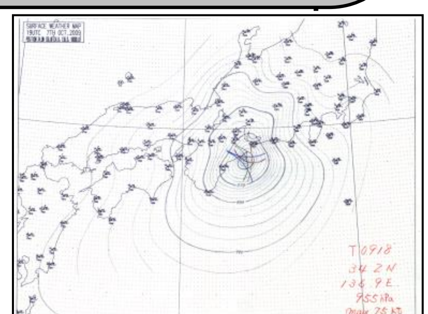
Radar

AMEDAS

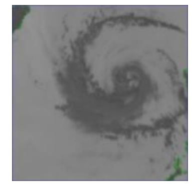
Available only when the TC is approaching Japan

Analysis of TC and weather chart

Applying all the observational data for both TC analysis and surface weather chart.

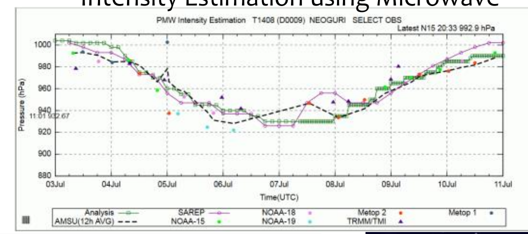


Irregular Observation



MW 36GHz

Intensity Estimation using Microwave



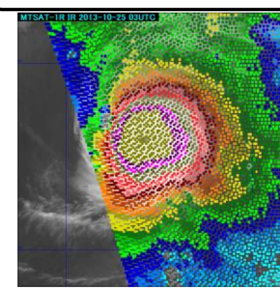
Microwave Imagery

Microwave Intensity Estimation

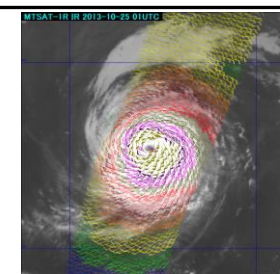
Microwave Scatterometer wind data

All-weather Sea Surface Wind Sped

Intensity of Estimation of lower cumulus convection, sea wind and warm core around the TC



All-Sky wind data

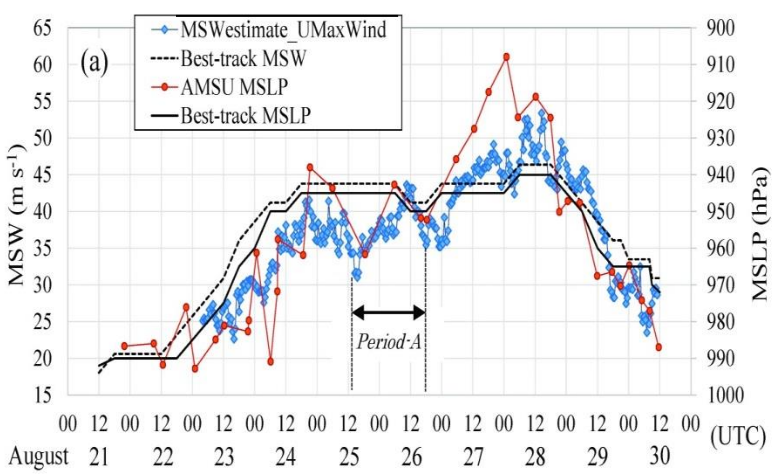


Scatterometer wind data

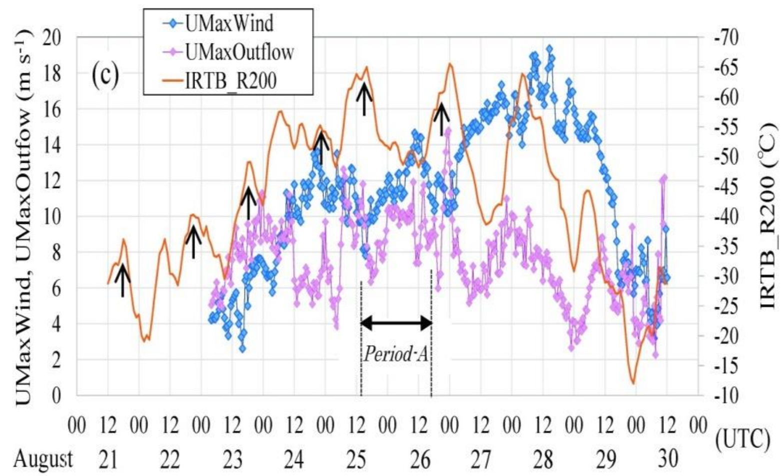
Himawari-8 RS-AMVs for Typhoons Analysis

- ✓ The maximum wind speed on the ground estimated from the maximum tangent wind of the upper tropospheric AMV well matches the maximum wind speed of the best track.
- ✓ The upper maximum outflows have correlation with the IR (band13) TBs of Himawari-8 averaged within the radius of 200 km of the TC center.

Tangential Wind



Outflow



Time sequence (every 30 min.) of tangential wind and outflow of upper-air AMV（100～300hPa）derived from Himawari-8 Region 3 observation（2.5min,1000x1000km）（T1610 case）

4. Data Assimilation and Forecast

a. Computer Resources and NWP Models
b. Data Assimilation
c. Forecast
d. Ensemble Forecasts

TC Track Forecast

Flow of TC Forecasting（track）

The latest products of operational Numerical Weather Prediction

↓

Confirmation of the skill of the earlier initial NWP products

↓

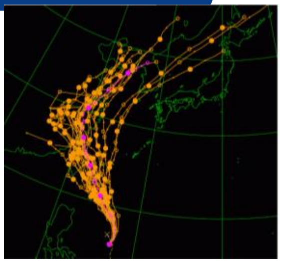
Correction the initial TC position

↓

TC Center Position, Direction, Speed and Radius of Probability circle

JMA Global Ensemble Prediction System

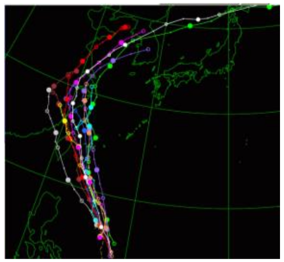
40km, L100, M27



JMA GSM

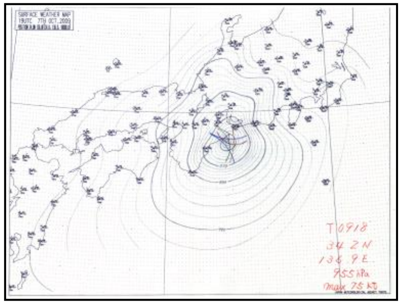
20km, L100

Other NWPs (ECMWF, NCEP etc)



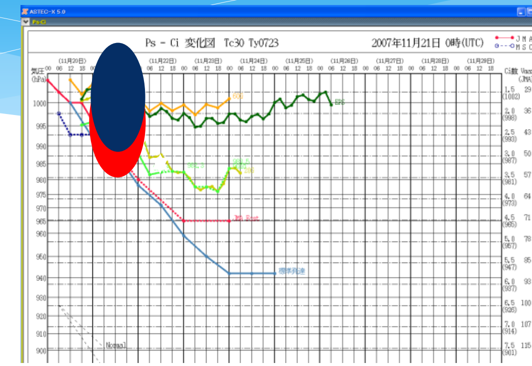
Observation

TC Analysis



Statics and Variability of EPS

TC Intensity Forecast



Flow of TC Forecasting (Intensity)

TC Analysis and Track Forecast

↓

Statistical model (SHIFOR)

NWP and correction the initial TC position

Statistical regression model (SHIPS)

Environment
（Atom., SST, TCHP, Topography etc）

↓

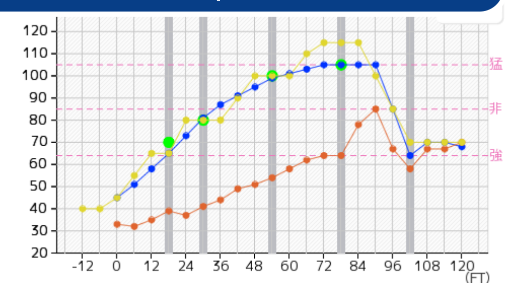
TC Intensity
(Center Pressure, Maximum sustained wind speed etc)

Climatology and Persistence

JMA GSM

Other NWPs
（ECMWF、NCEP etc）

Statistical Hurricane Intensity Prediction System
- Trial operation -

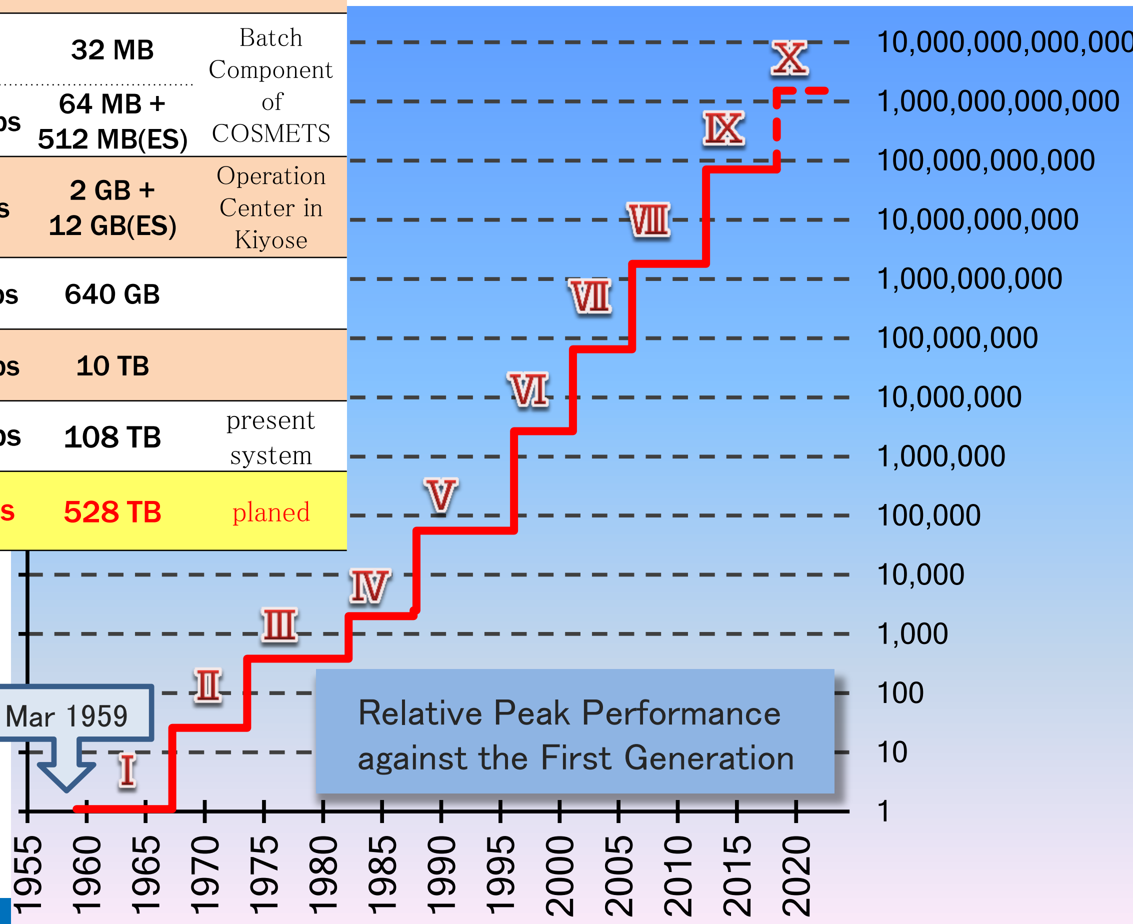


Computer Resources for NWP Operation

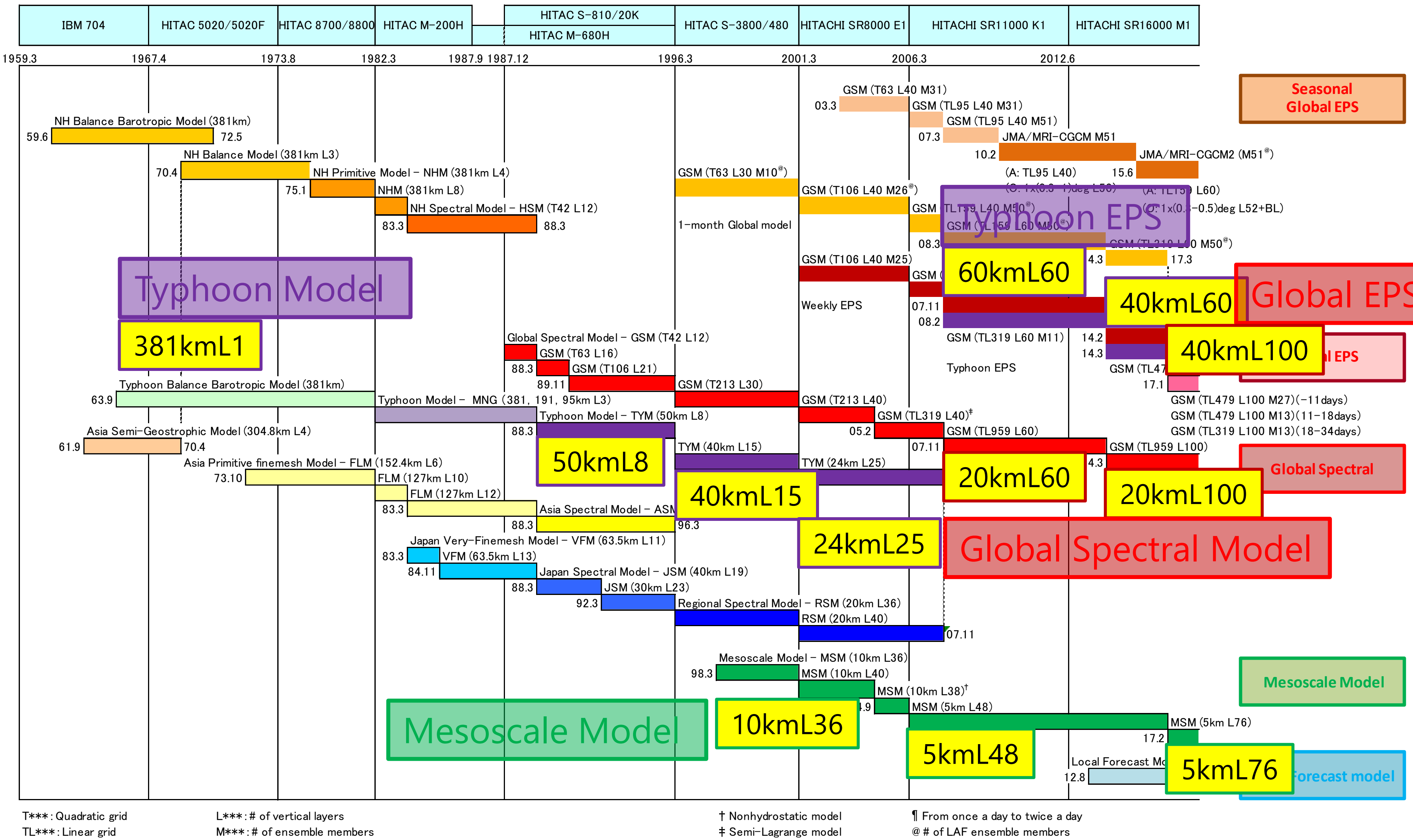
Generation	Date of operation	Main frame	Peak performance	Main memory	Note
I	1959/3	IBM-704	84 μsec	8 KW (36bit)	JMA HQs in Otemachi
II	1967/4	HITAC-5020F	3.25 μsec	131 KW (32bit)	
III	1973/8	HITAC-8700/8800	0.22 μsec	2 MB	
IV	1982/3	HITAC-M200H x2	0.084 μsec	16 MB	
V	1987/9	HITAC-M680	30 MIPS	32 MB	Batch Component of COSMETS
	1987/12	HITAC-S810	630 MFlops	64 MB + 512 MB(ES)	
VI	1996/3	HITAC-S3800_480	32 GFlops	2 GB + 12 GB(ES)	Operation Center in Kiyose
VII	2001/3	HITACHI-SR8000E1	768 GFlops	640 GB	
VIII	2006/3	HITACHI-SR11000K1 x2	21.5 TFlops	10 TB	
IX	2012/6	HITACHI-SR16000M1 x2	847 TFlops	108 TB	present system
X	2018/6	CRAY XC50 X2	18 PFlops	528 TB	planed

SR16000M1(2012-)

Planed XC50 (image)(2018-)



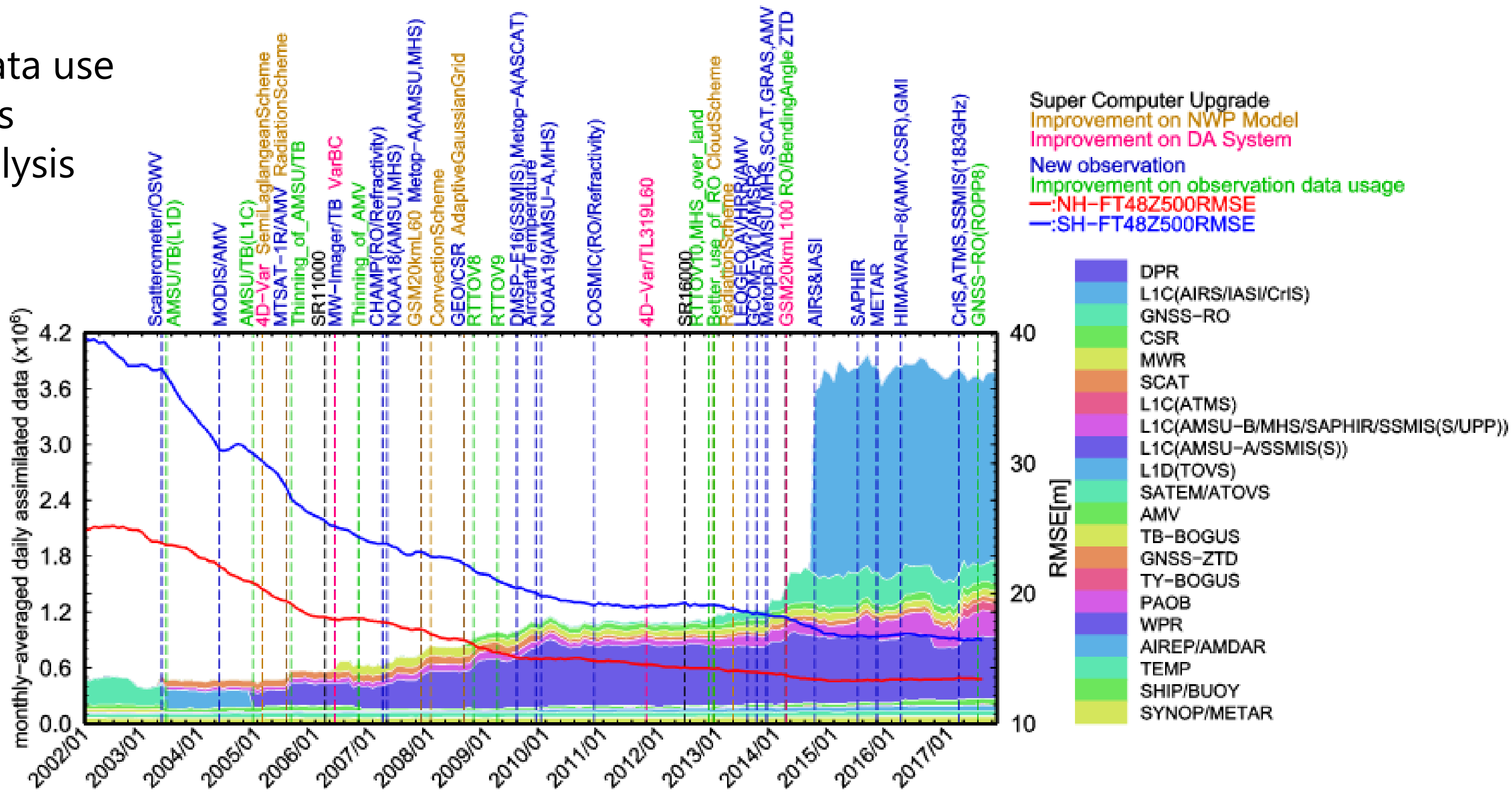
Operational NWP Models



Operational Data Assimilation for TC Forecasts

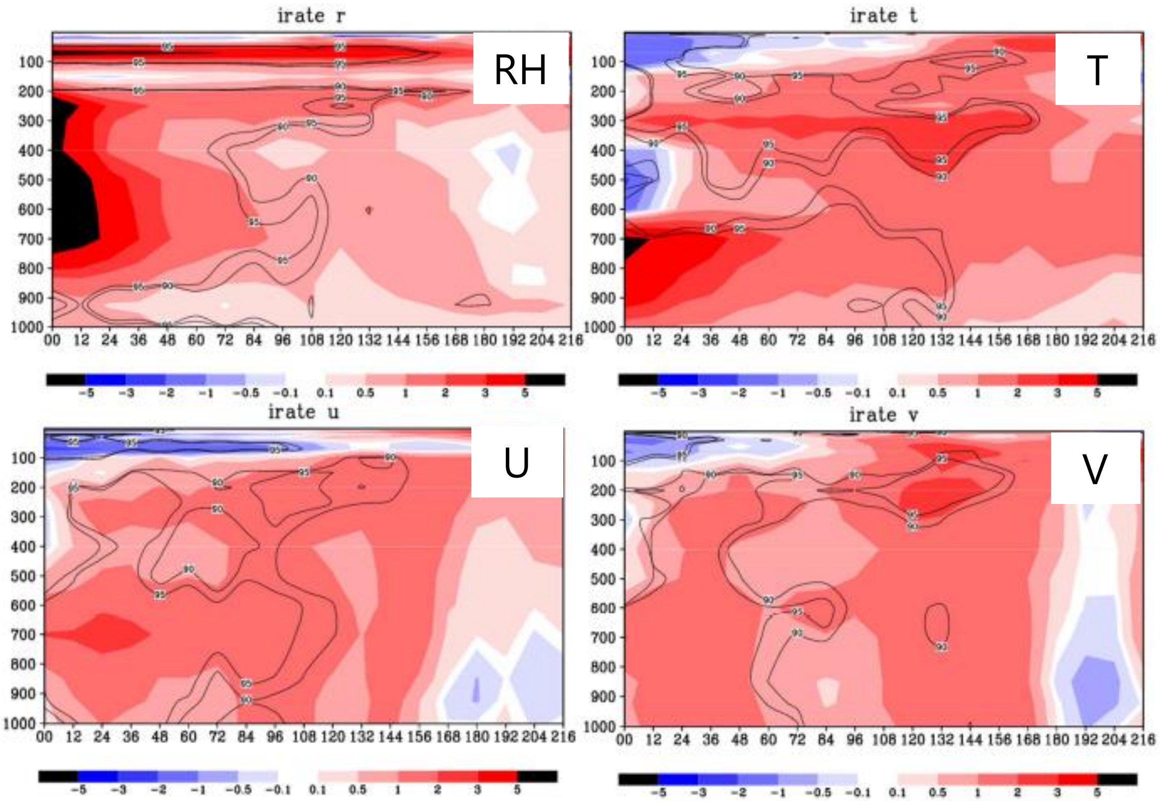
- ✓ JMA has implemented a 4D-Var data assimilation system in 2005 for JMA's Global Analysis. By using the system, a variety of data come to be effectively used.
- ✓ Effective observation data for TC forecasts are AMVs, GNSS-RO, microwave sounder (ATMS etc.) and scatterometer (SCAT) which give information on thermal structure and water vaper transport around tropical cyclones.
- ✓ Data volume available for assimilation has been exploding in recent years especially after introducing hyper-spectral sounders (AIRS/IASI/CrIS).

Trend of data use in the JMA's Global Analysis

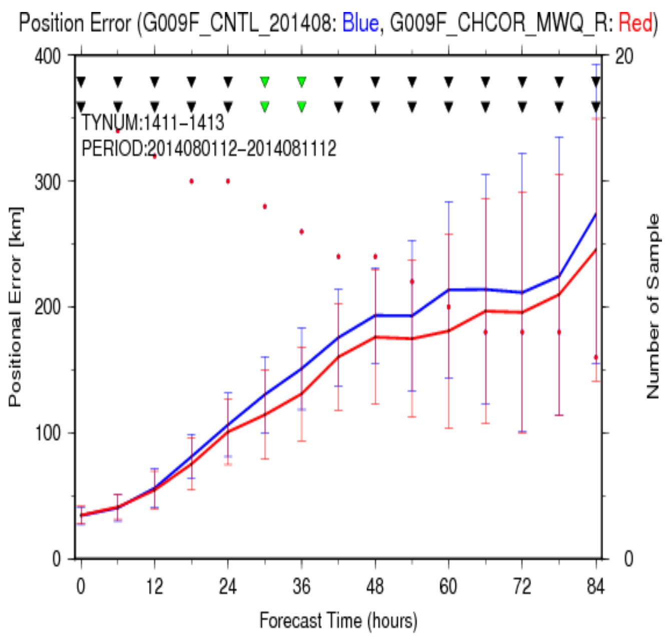


Data Assimilation of Multi-channel Data

- ✓ JMA/MRI developed an assimilation scheme that considered observation error cross-correlation between satellite water vapor channels for JMA's GSM.
- ✓ Result of the experimental cycle experiments using the above scheme for August 2014 shows remarkable forecast improvements.



Forecast improvement rate (00 – 216h)
(**red: positive**, **blue: negative**)

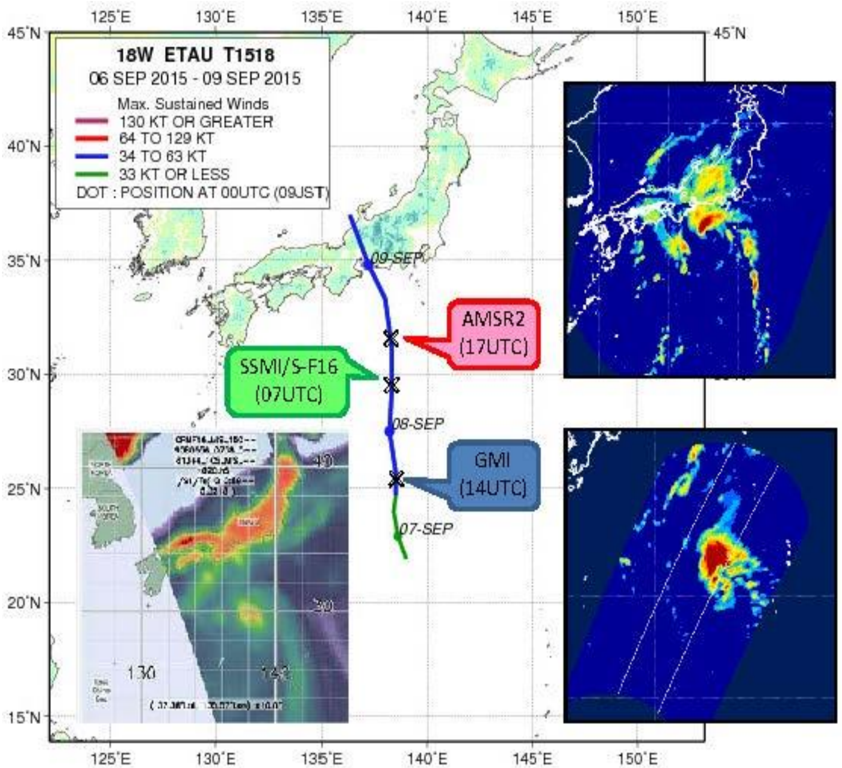


TC track forecast error (00 – 84h)
(Red : TEST, Blue : Conventional)

Data Assimilation under All Weather Conditions

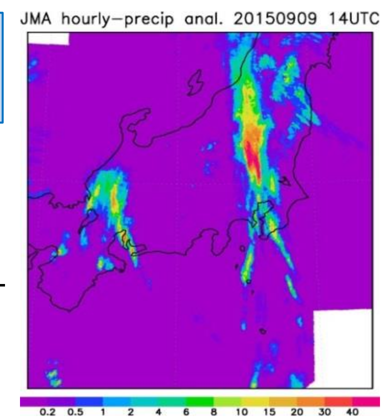
- ✓ JMA/MRI has constructed a forecast analysis (FA) system of an EnVAR scheme for a cloud resolving model (CRM).
- ✓ Assimilation of GMI, AMSR2, and SSMIS TBs using the system for Typhoon Etau gave large forecast improvement of precipitation bands over Kanto plain.

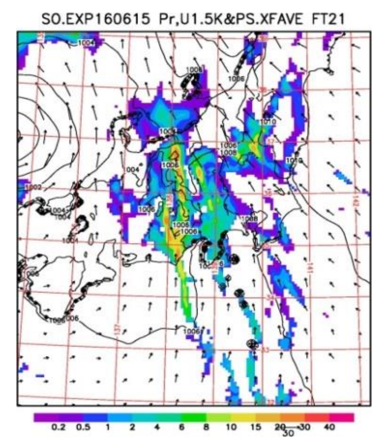
The track of Typhoon Etau (T1518) and MWI TBs assimilated with the EnVAR FA system



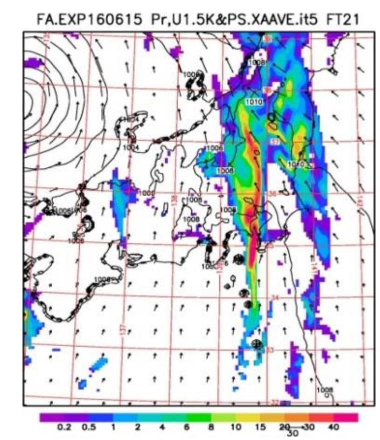
Hourly precipitation (mm) for 14UTC 9th Sep. 2015

JMA Radar-gauge analysis



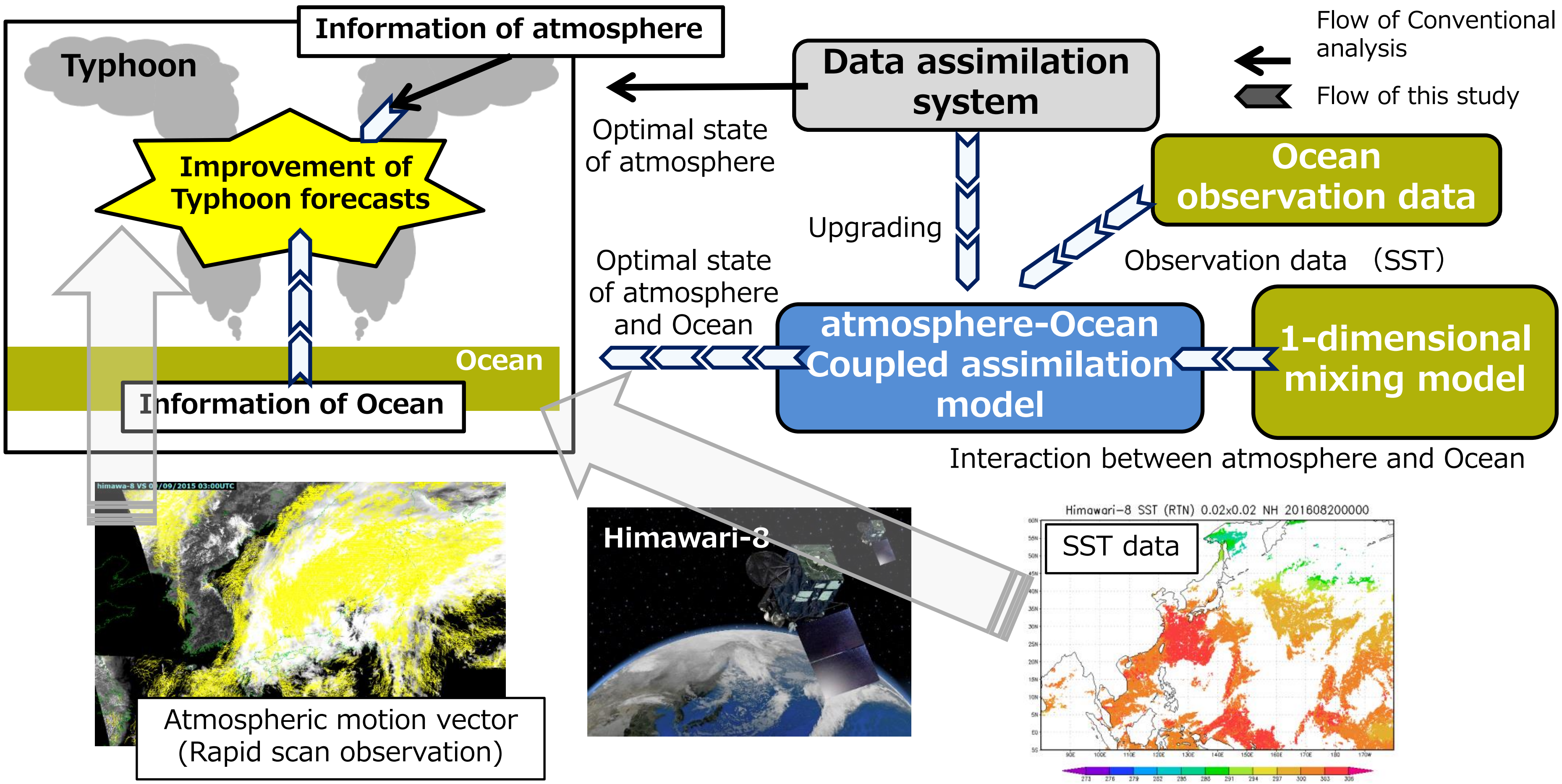


CRM 21h fcst. w/o MWI



with MWI

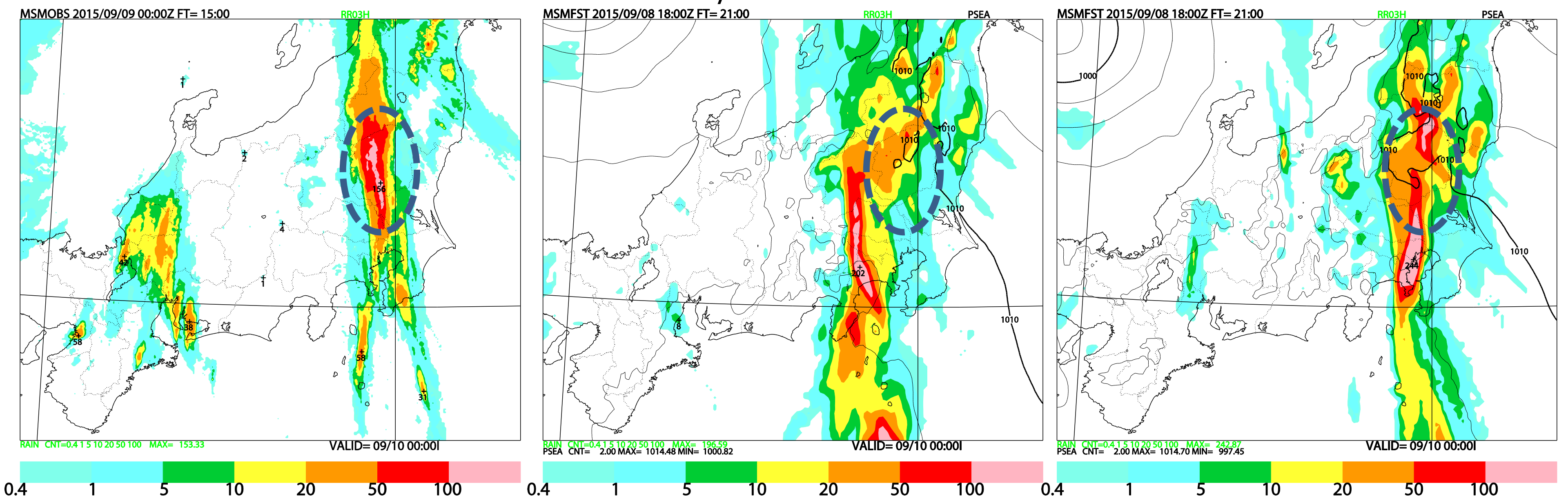
Himawari Rapid Scan AMVs and Atmosphere-Ocean Coupled Assimilation



Himawari Rapid Scan AMVs and Atmosphere-Ocean Coupled Assimilation

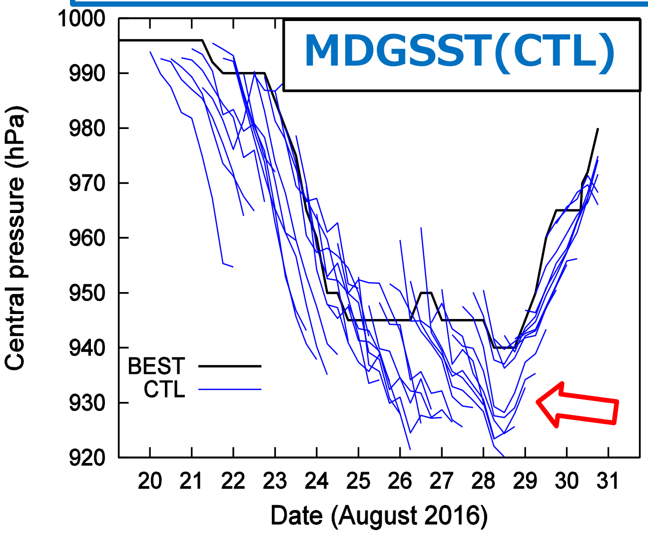
- ✓ Heavy rainfall occurred over Kanto and Tohoku districts on September 9-11, 2015.
- ✓ Convergence of southerly and southeasterly flows caused the stationary rainfall band of the heavy rainfall.
- ✓ Maximum 24 hour rainfall reached 541 mm. Himawari-8 AMVs captured distinctly the convergence causing rain band (not shown).
- ✓ As a result, Himawari-8 AMVs improved the forecast of position of the rainfall band that caused the heavy rainfall

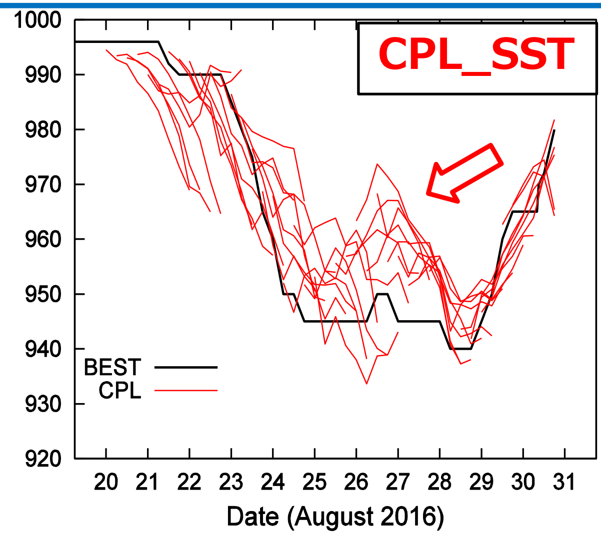
OBS | Forecast w/o Raid scan AMV | Forecast with Raid scan AMV

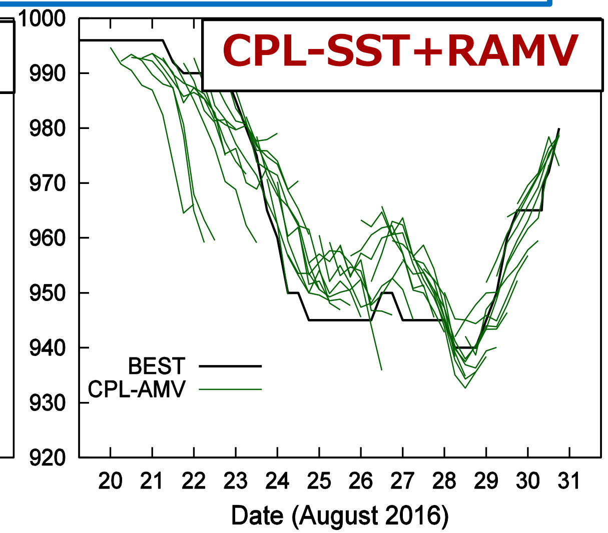


Himawari Rapid Scan AMVs and Atmosphere-Ocean Coupled Assimilation

- ✓ To estimate the impact of rapid scan AMVs on TC intensity, observation system experiments were performed for August 2017.
- ✓ The atmosphere-ocean coupling model succeeded in suppressing the development of typhoon though the intensity peak is shallower than the best track.
- ✓ The intensity forecast becomes closer to the observed one by assimilation of the Himawari-8 rapid-scan AMVs.







When MGDSST is used, central pressure becomes lower than the best track.

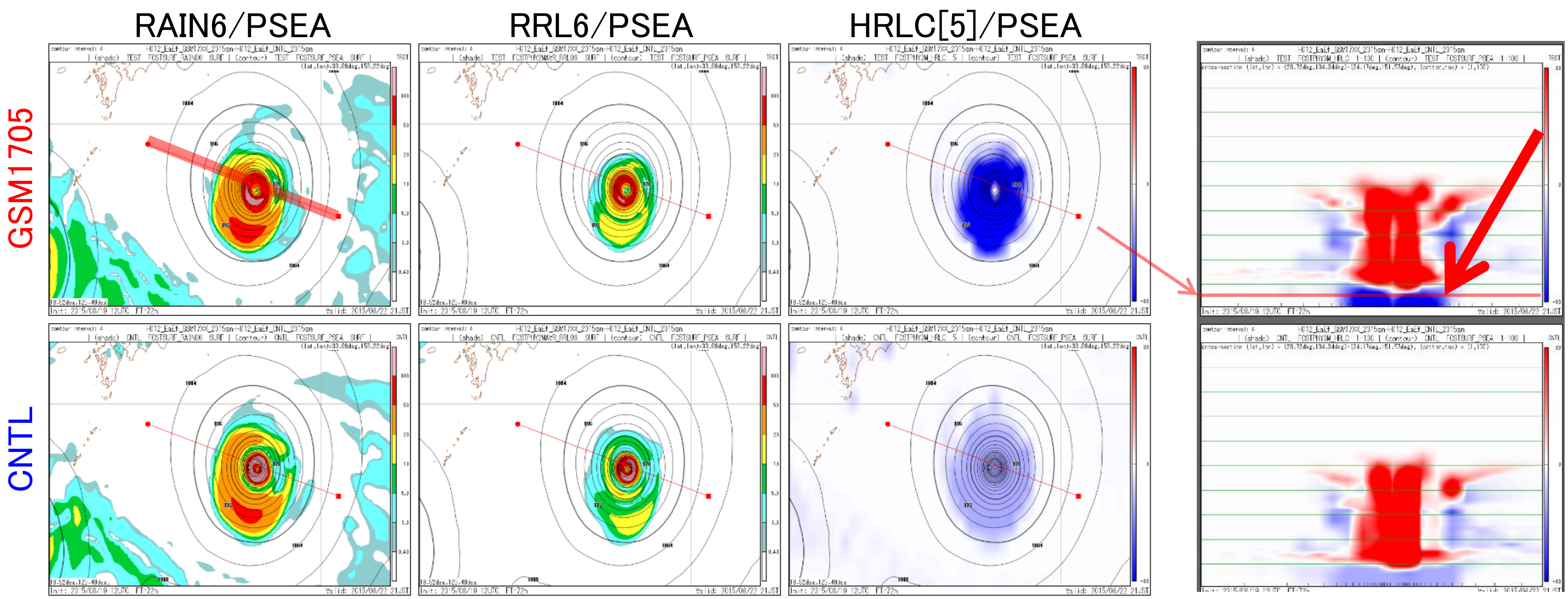
Atmosphere-Ocean coupling model suppresses the development of Typhoon.

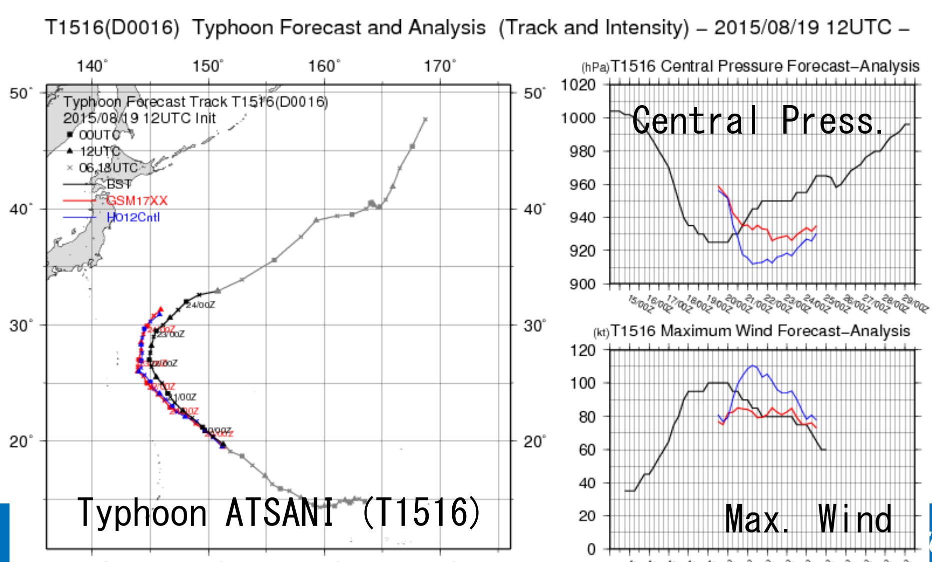
The intensity becomes closer to the observed one by assimilation of rapid-scan AMV.

Forecast from all initial times are plotted.

— Best track, — — — Intensity obtained by each experiment

Operational TC Forecasts with Global NWP Model





- ✓ The renewal of GSM was in operation on May 2017.
- ✓ Excess development of typhoon is suppressed by expressing cooling in lower troposphere properly.
- ✓ Expression of melting layer is also refined.

High-resolution Global Model Simulation

- ✓ JMA/MRI and JAMSTEC/CEIST jointly performed the "Global 7-km mesh nonhydrostatic model inter-comparison project for improving typhoon forecast (TYMIP-G7)"
- ✓ An updated cumulus scheme of MRI's global NWP model improved: 1) statistic 9-day forecast skill, in particular, over the extra-tropical northern hemisphere, and 2) rain distribution around TC centers in high-resolution (7km) experiments.

MRI-NAPEX improvement rate

Old

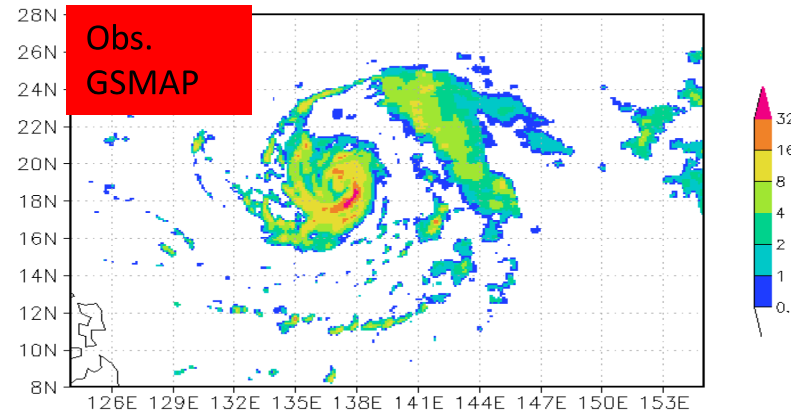
9-days	PseaSurf [hour]	T850	Z500 [hour]	Wspd850	Wspd250 [hour]
Global	-2.41	2.51	-3.33	-0.75	-3.37
N. Hem.	2.86	3.76	-0.23	0.04	-1.20
Tropics	5.08	11.65	1.72	3.07	-1.96
S. Hem.	-4.75	-0.75	-4.74	-2.41	-5.82

Rate of Improvement (Average) [%]

New

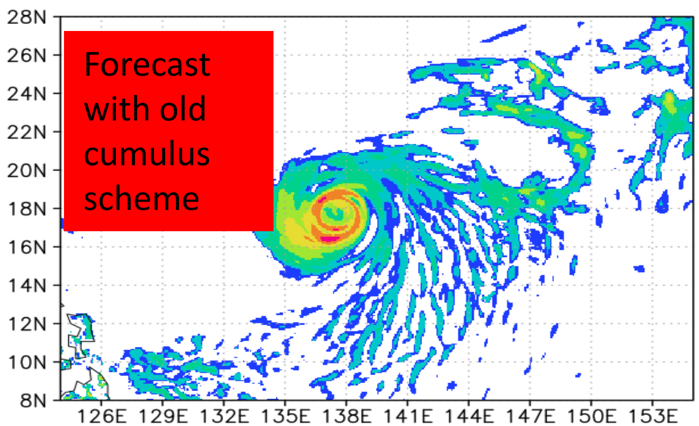
9-days	PseaSurf [hour]	T850	Z500 [hour]	Wspd850	Wspd250 [hour]
Global	-0.66	5.69	-1.27	0.35	-1.75
N. Hem.	4.36	7.81	2.08	1.44	0.86
Tropics	9.01	18.86	8.11	4.66	0.32
S. Hem.	-3.08	1.07	-2.92	-1.58	-4.84

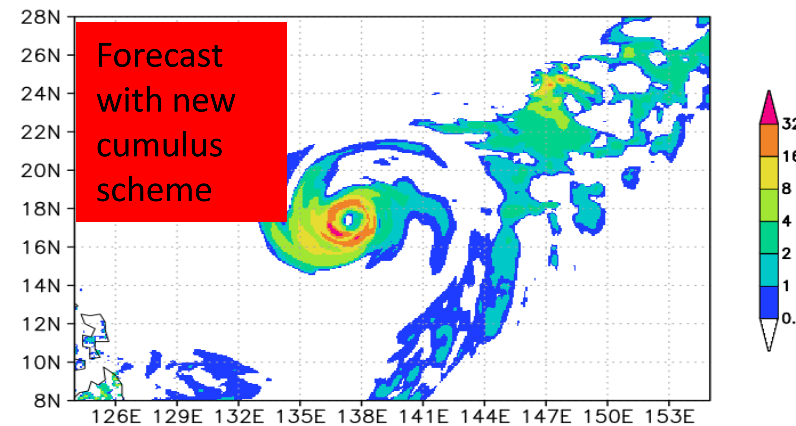
Rate of Improvement (Average) [%]



High-resolution (7km) TC forecast experiments

Forecast for 05UTC Oct. 13, 2013
Initial time: 12UTC Oct. 10, 2013

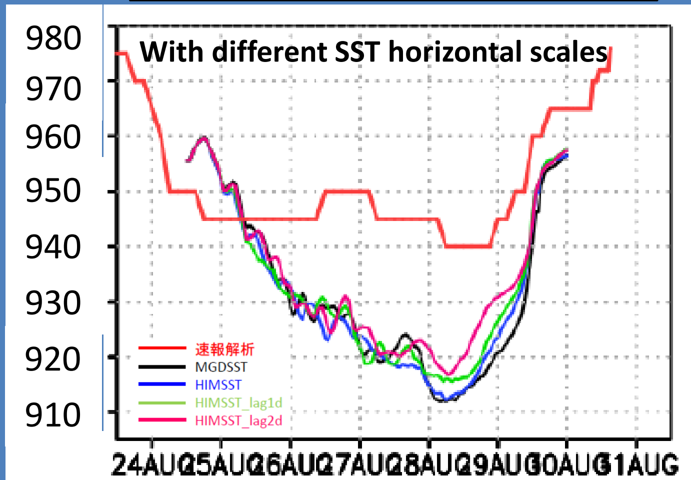


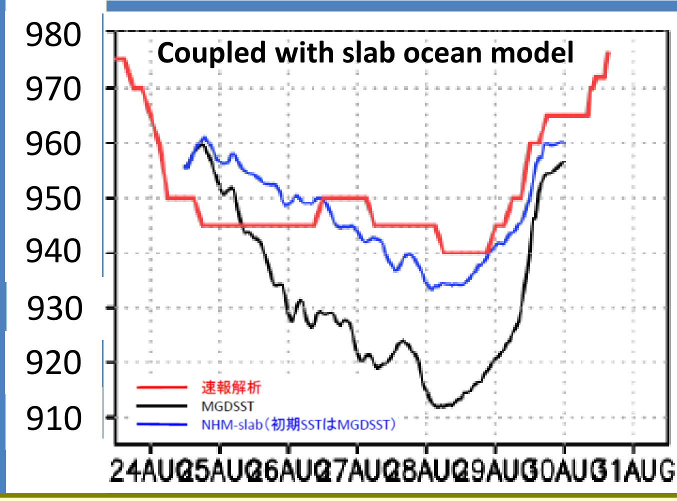


TC Forecast with a Coupling Model

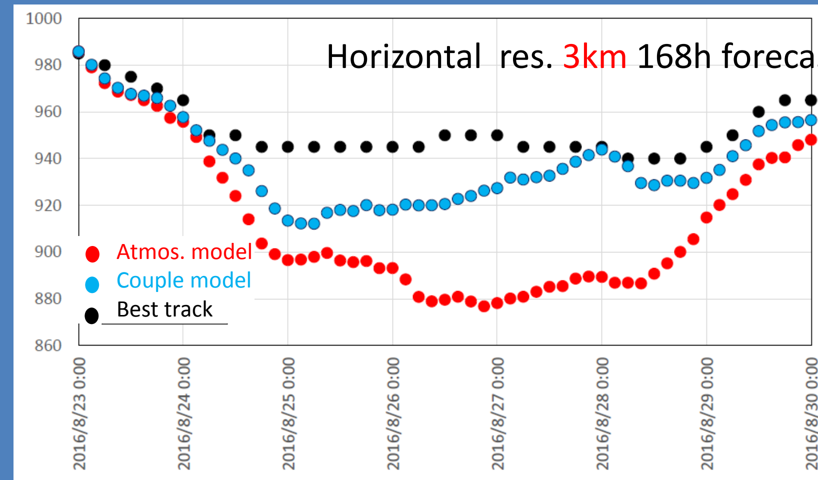
Experiments for T1610

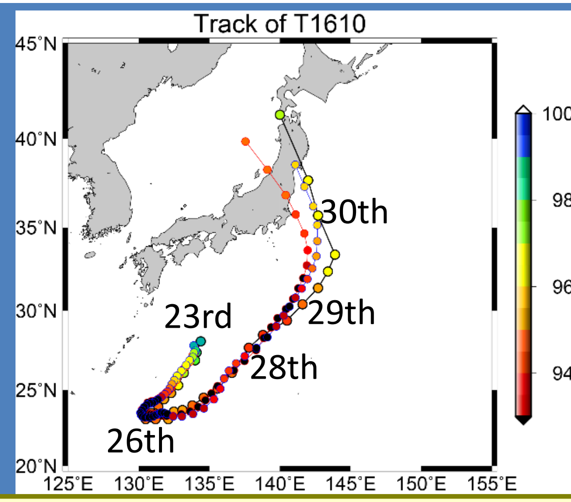
NHM5km 120h forecast





NHM Atmos.-Ocean-Wave couple model

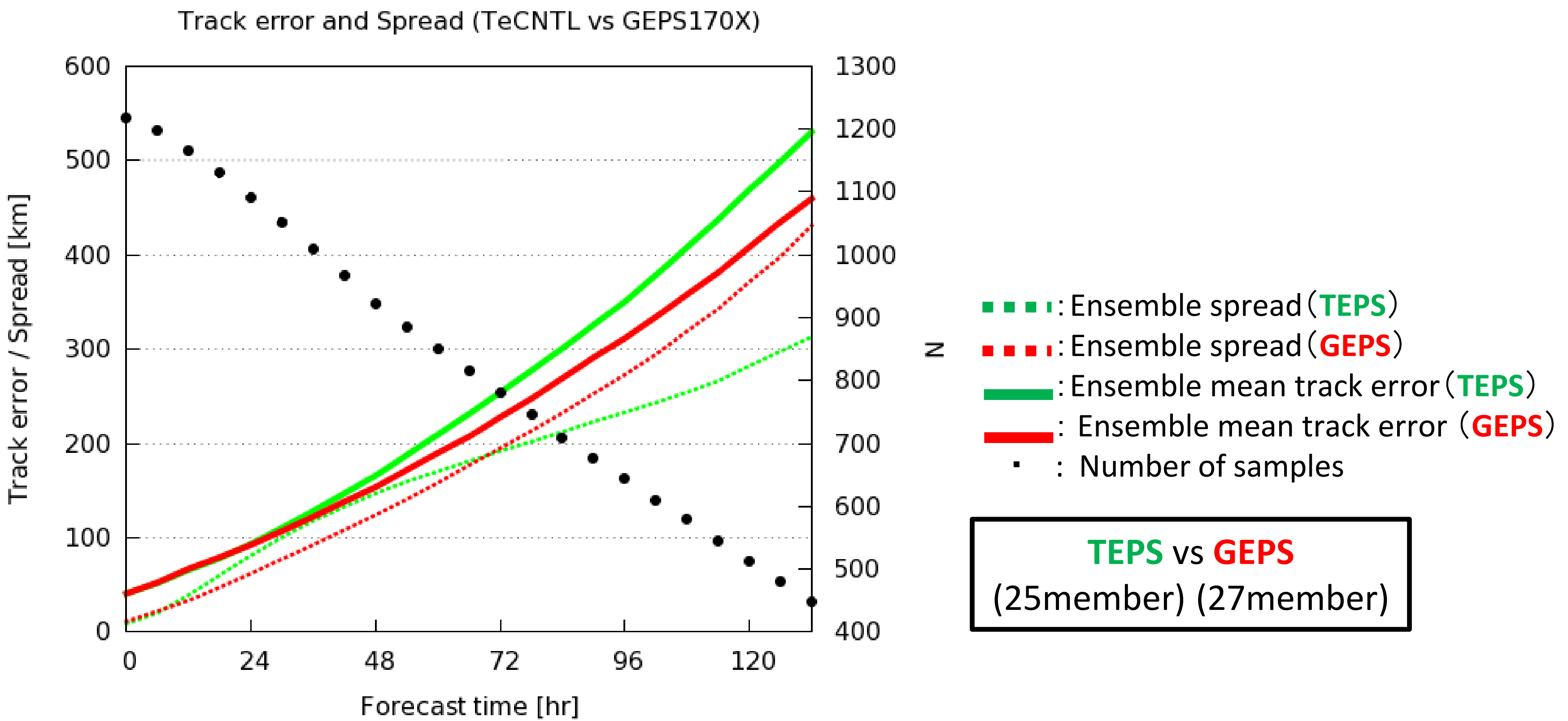




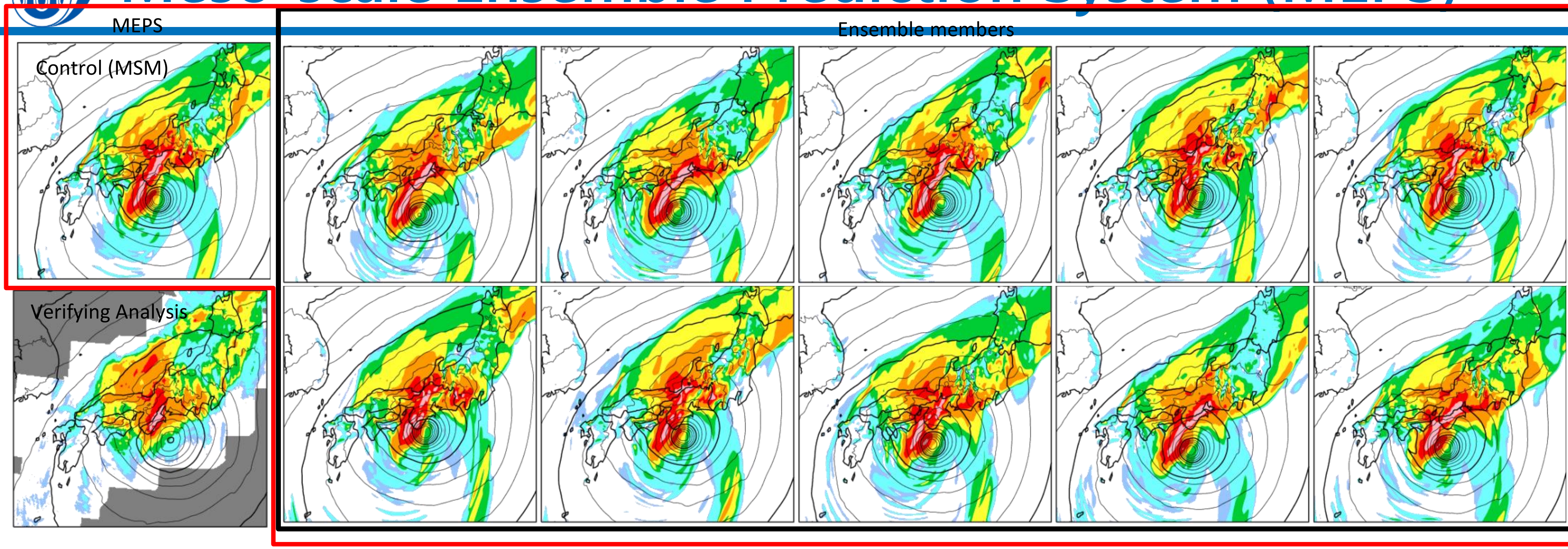
- ✓ The impact of ocean-coupling on the TC intensity forecast was larger than that of change in SST horizontal resolutions.

Global Ensemble Prediction System (GEPS)

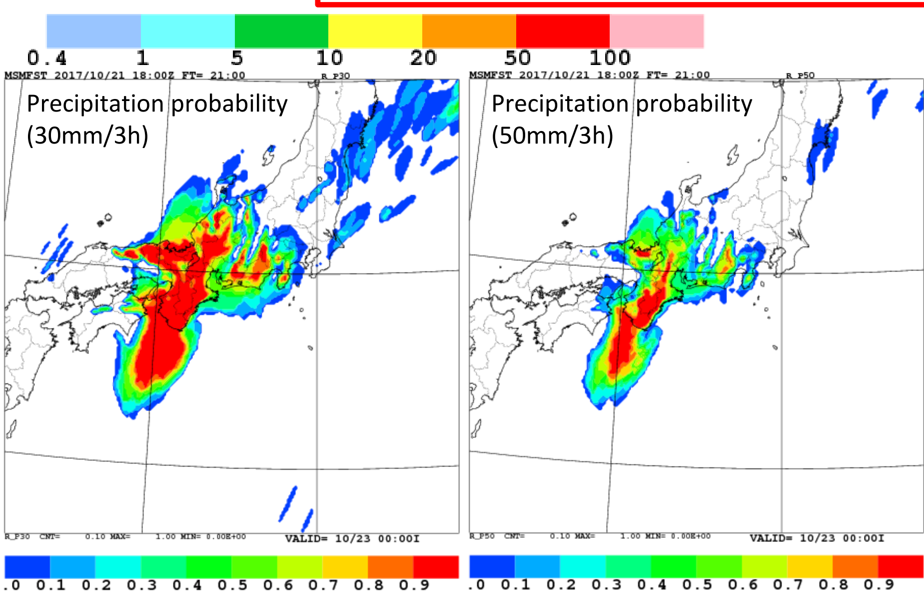
- ✓ JMA has operated the Global Ensemble Prediction System (GEPS) by unifying the previous Typhoon Ensemble Prediction System (TEPS) and One-week Ensemble Prediction System since January 2017.
- ✓ Ensemble mean track error of GEPS is remarkably smaller than that of TEPS.
- ✓ Ensemble spread of GEPS suits well with Ensemble mean track error.



Meso-scale Ensemble Prediction System (MEPS)



INIT: 21 OCT 2017 18UTC FT21. VALID: 22 OCT 2017 15UTC. Psea & R3



INIT: 21 OCT 2017 18UTC FT21. VALID: 22 OCT 2017 15UTC. Precipitation probability.

Typhoon LAN (1721)

- ✓ A Meso-scale Ensemble Prediction System (MEPS) of JMA is in the pre-operational stage in 2017.
- ✓ One of the major purposes is the probability forecasts for heavy rain system.
- ✓ TC related precipitation probability forecast is also important when a TC make landfall in Japan.

5. Summary

* Over the fifty years, TC observation, analysis and forecast technology and related infrastructure has improved dramatically. The stakeholders of national meteorological hydrological services require risk-based information with lead time which is assured by scientific based accurate forecasts with probability estimation.
* Now we face some difficulties on exploding data volume, increasing assimilation and model resolution as well as increasing ensemble size.
* We should continue try to way forward to new services under the support of new technologies such as advanced observation instruments, new computing architecture, high-speed communication technology and evolving artificial intelligence.