Activities of Numerical Weather Prediction for Typhoon forecast at Japan Meteorological Agency

Masayuki Nakagawa

Numerical Prediction Division

Japan Meteorological Agency

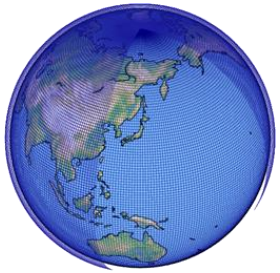
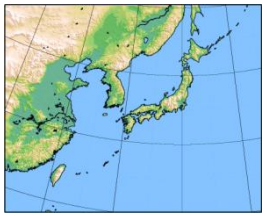
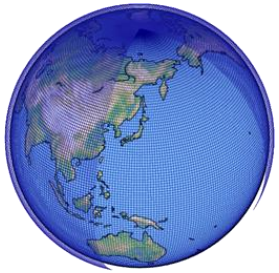
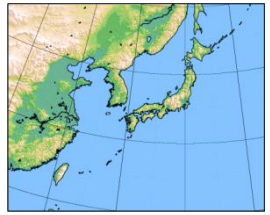
ESCAP/WMO Typhoon Committee Forty-ninth Session

21 February 2017, Yokohama

Contents

1. Recent progress in the JMA global NWP system
   - Deterministic prediction system
   - Ensemble prediction system
2. WGNE intercomparison of tropical cyclone track forecast
3. Future plan and summary

Current NWP models of NPD/JMA

	In Operation				In Test Operation
	Global Spectral Model GSM	**Meso-Scale Model MSM**	**Local Forecast Model LFM**	**Global Ensemble GEPS**	**Meso-scale Ensemble MEPS**
objectives	Short- and Medium-range forecast	Disaster reduction Aviation forecast	Aviation forecast Disaster reduction	One-week forecast Typhoon forecast	Uncertainty and probabilistic information of MSM
Forecast domain	Global 	Japan and its surroundings (4080km x 3300km) 	Japan and its surroundings (3160km x 2600km) 	Global 	Japan and its surroundings (4080km x 3300km) 
Horizontal resolution	TL959(0.1875 deg)	5km	2km	TL479(0.375 deg)	5km
Vertical levels / Top	100 0.01 hPa	48+2 21.8km	58 20.2km	100 0.01 hPa	48+2 21.8km
Forecast Hours (Initial time)	84 hours (00, 06, 18 UTC) 264 hours (12 UTC)	39 hours (00, 03, 06, 09, 12, 15, 18, 21 UTC)	9 hours (00-23 UTC hourly)	264 h (00, 12 UTC) 132 h (06, 18 UTC)* 27 members	39h 11 members
Initial Condition	Global Analysis (4D-Var)	Meso-scale Analysis (4D-Var)	Local Analysis (3D-Var)	Global Analysis with ensemble perturbations (SV, LETKF)	Meso-scale Analysis with ensemble perturbations (SV)

* when a TC of TS intensity or higher is present or expected in the RSMC Tokyo - Typhoon Center's area of responsibility (0º–60ºN, 100ºE–180º).

RECENT PROGRESS IN THE JMA GLOBAL NWP SYSTEM

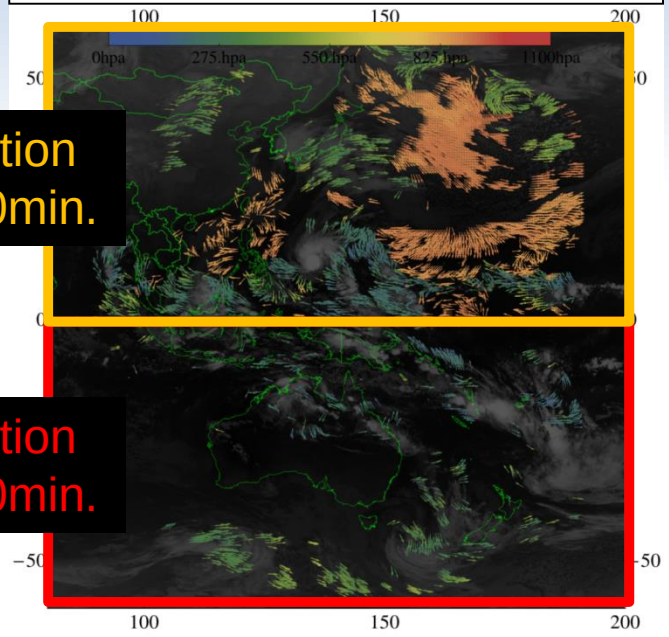
- DETERMINISTIC -

Recent progress - deterministic -

- 18 Mar. 2014: Major upgrade was made especially to the model. Major changes were,
  - increase in the resolution from TL959L60 to TL959L100 with a topmost level raised from 0.1hPa to 0.01hPa,
  - revision of several physical processes such as boundary layer, radiation, non-orographic gravity wave and deep convection.
  - The assimilation of AMSU-A channel 14 and ground-based GNSS-ZTD (Zenith Total Delay) data were started, and the GNSS RO assimilation was revised from refractivity assimilation up to 30 km AMSL to bending angle assimilation up to 60 km AMSL.
- 04 Sep. 2014: Assimilation of Metop-A/IASI, Metop-B/IASI, and Aqua/AIRS started.
- 25 Jun. 2015: Assimilation of Megha-Tropiques/SAPHIR started.
- 08 Oct. 2015: Assimilation of METAR surface pressure data started. Usage of ASCAT ocean surface wind vector data was improved.
- ***17 Mar. 2016: Assimilation of Himawari-8 AMV and CSR data started.***
- ***24 Mar. 2016: Major upgrade was made to the model. Major changes were,***
  - ***The parameterization schemes of the Global Spectral Model (GSM) such as land surface processes, deep convection, cloud, radiation, sea ice and so on were revised.***
  - ***Assimilation of the GPM Microwave Imager (GMI) data started.***
- 28 Sep. 2016: The typhoon bogus scheme was revised.
- 15 Dec. 2016: Quality Control for Himawari-8 AMV was revised. Assimilation of GRACE-B/BlackJack radio occultation data was enabled.

Enhancement on AMV and CSR in Mar. 2016

MTSAT-2 AMV



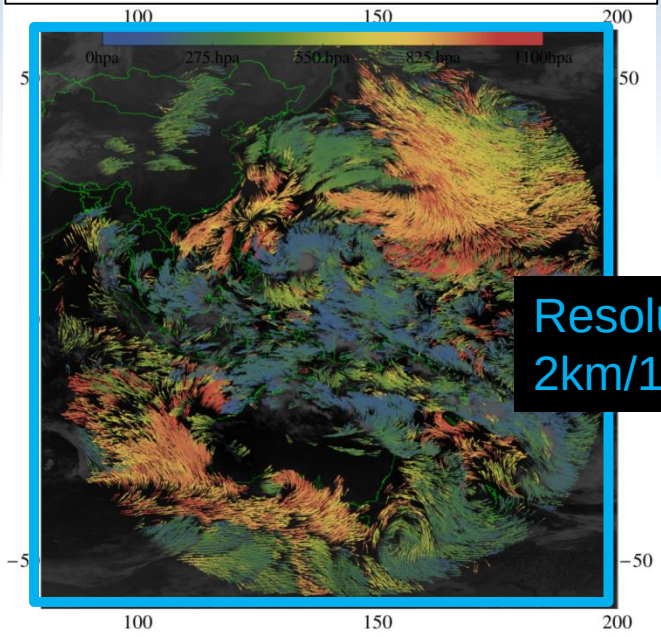
Resolution 4km/30min.

Resolution 4km/60min.

Cold colors: Upper winds
Warm colors: Lower winds

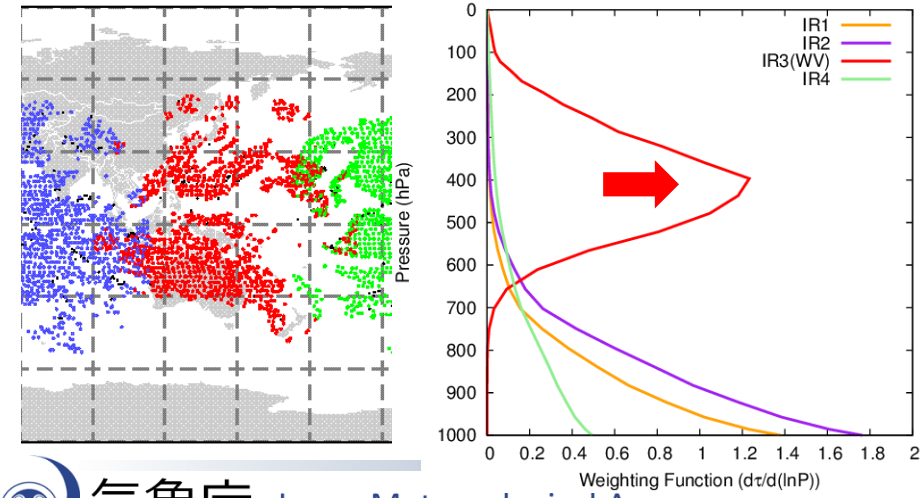
(QI>60, 2015.01.14 17:00UTC)

Himawari-8 AMV

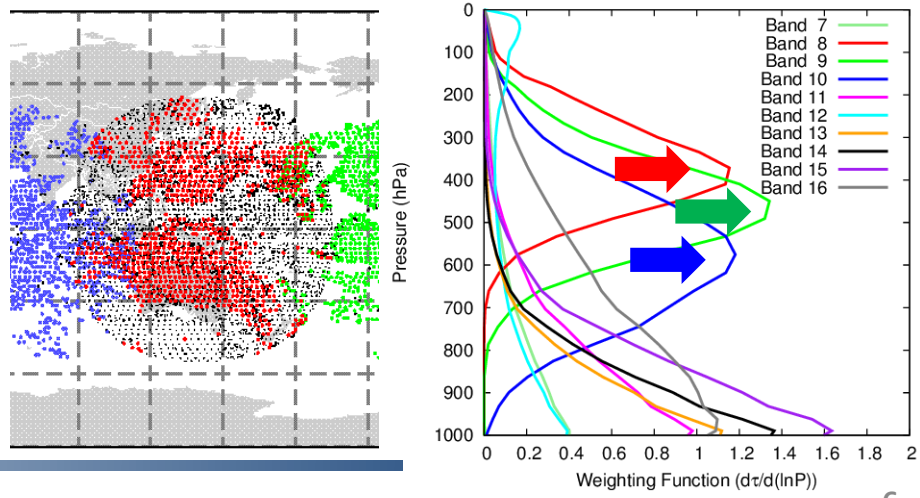


Resolution 2km/10min.

MTSAT-2 CSR

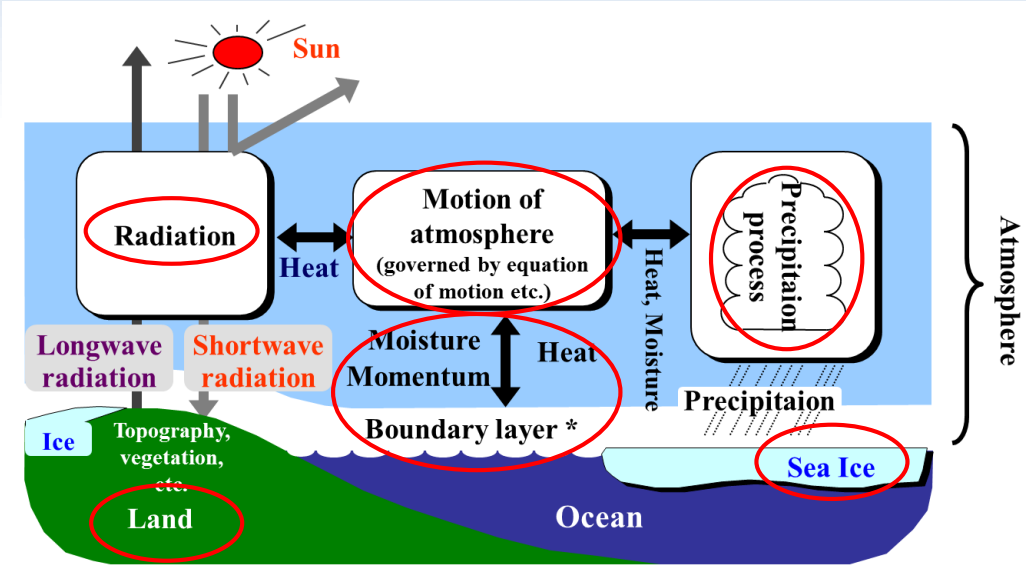


Himawari-8 CSR



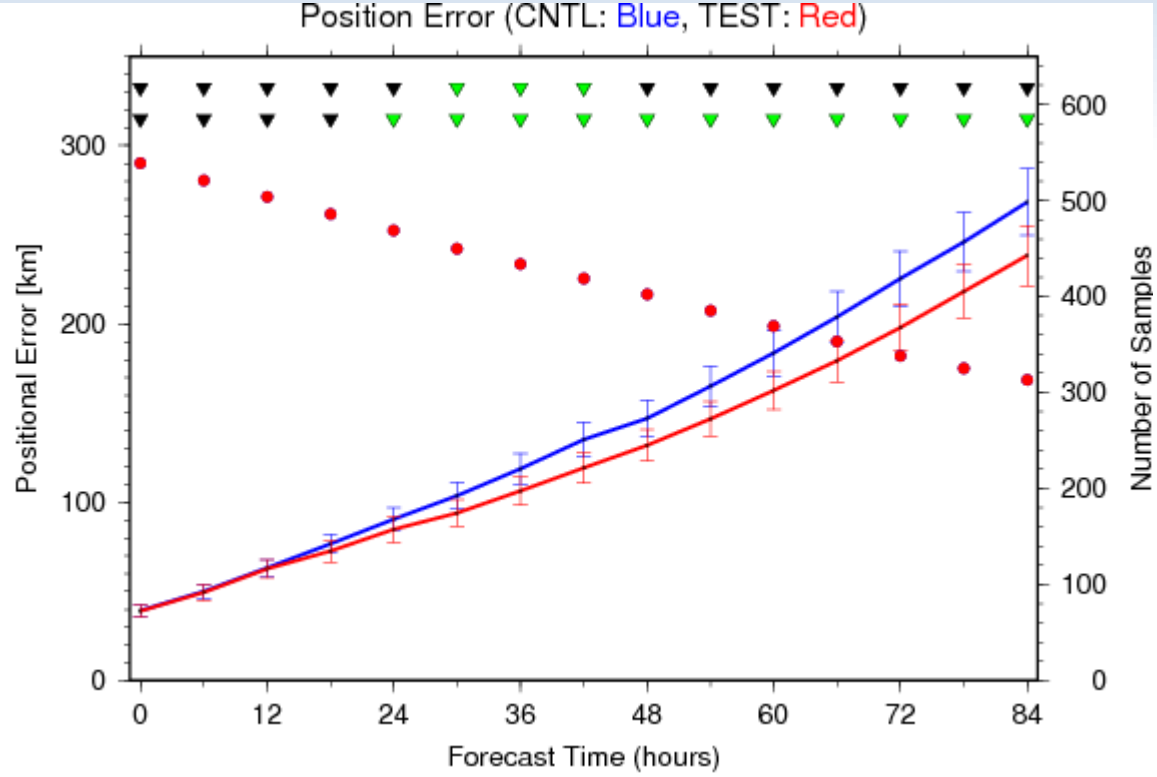
Upgrade of the global NWP system in Mar. 2016

- Implementation of a new land surface model (LSM) named “improved SiB (iSiB)”.
- Upgrade of the deep convection parameterization.
- Upgrade of the cloud scheme.
- Upgrade of the radiation scheme.
- Upgrade parameterizations for sea surface fluxes.
- Upgrade of treatment of sea ice.
- Optimization of Legendre Transformation, which is a part of spectral transformation on a sphere



- Start of assimilating new observations in the analysis
  - Assimilating GPM Microwave Imager data (new use)
  - Assimilation of Himawari-8 Atmospheric Motion Vectors (AMV) and Clear Sky Radiances (CSR)

Improvement in typhoon track forecast

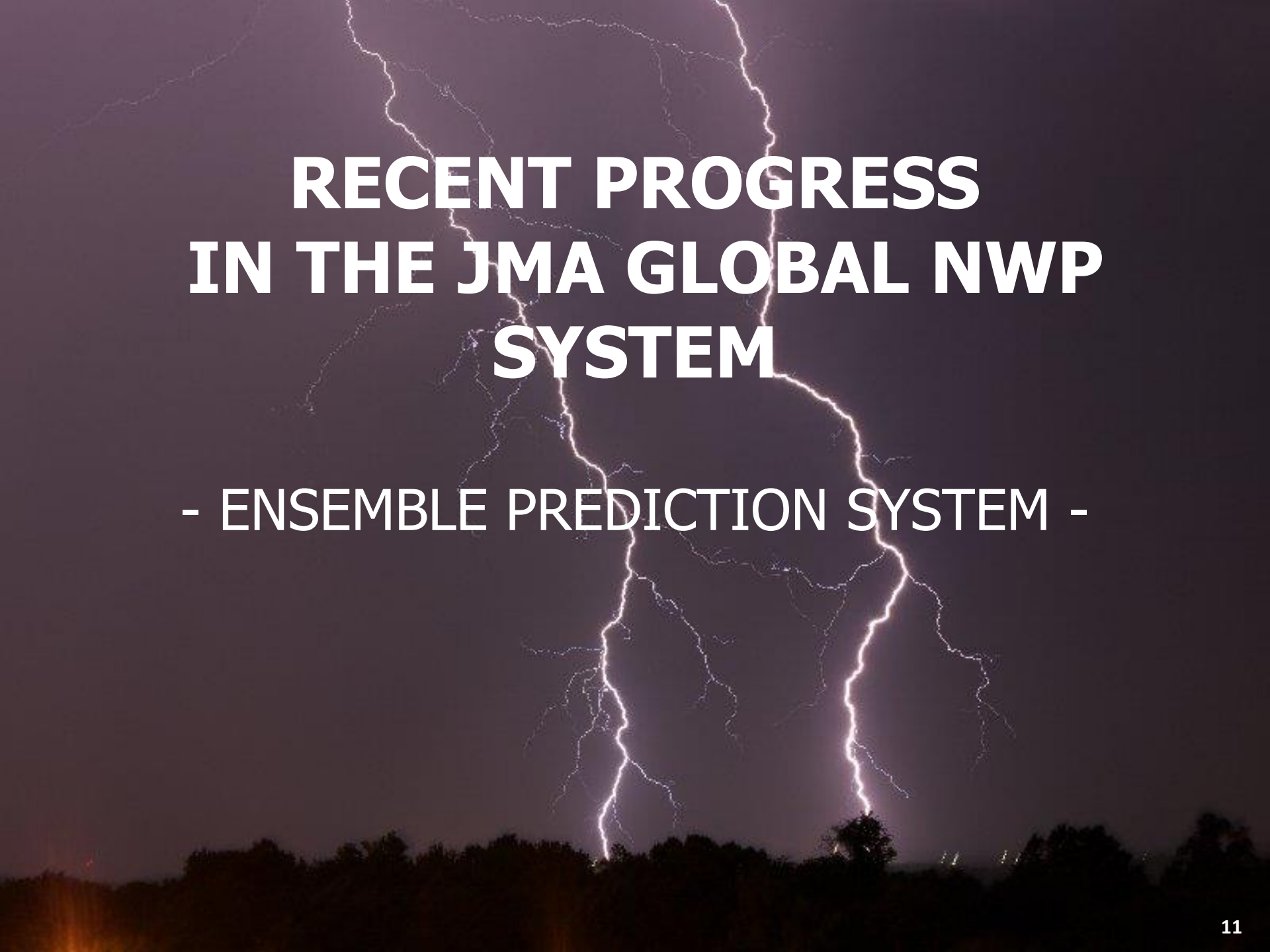


Typhoon track errors
(T1508 – T1523)

– : OLD
– : NEW
●: NUM

I : 95% confidence interval
▼ : statistically significant

The upgrades significantly reduce typhoon track forecast errors.
Both assimilation of Himawari-8 AMV and CSR and upgrade of forecast model contribute to the improvement.



RECENT PROGRESS IN THE JMA GLOBAL NWP SYSTEM

- ENSEMBLE PREDICTION SYSTEM -

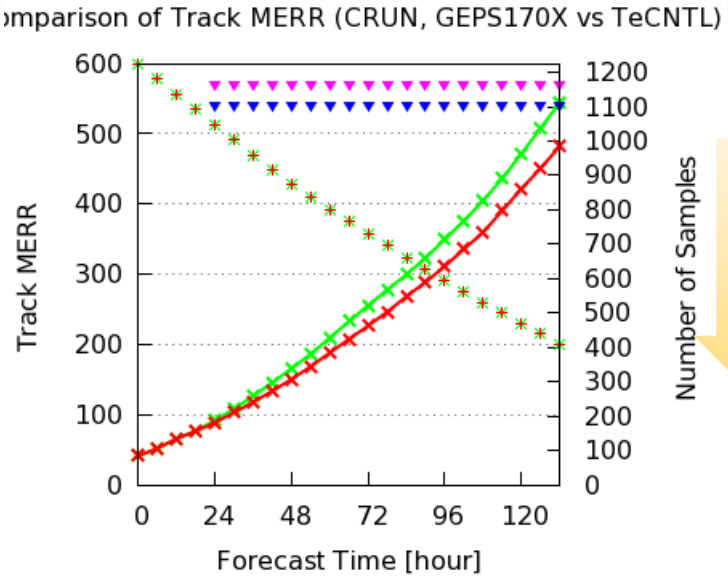
Recent progress - EPS -

- 26 Feb. 2014: One-week EPS was upgraded. Major changes were,
  - increase in model resolution (from TL319L60 to TL479L60)
  - increase in frequency of operation (from once a day to twice a day)
- 11 Mar. 2014: Typhoon EPS was upgraded. Major changes were,
  - increase in model resolution (from TL319L60 to TL479L60)
  - increase of ensemble members (from 11 to 25)
- ***19 Jan. 2017: Operation of Global EPS started.***
  - ***One-week EPS and Typhoon EPS were unified and renamed to Global EPS***
  - ***The number of vertical layers of the Global EPS model was increased from 60 to 100, and the pressure of the top level was raised from 0.1 hPa to 0.01 hPa.***
  - ***Perturbations from LETKF were introduced for initial perturbations.***
  - ***Perturbations to sea surface temperature were introduced.***
- ?? 2017: Unification of One-month EPS into Global EPS

Improvement in typhoon track forecast

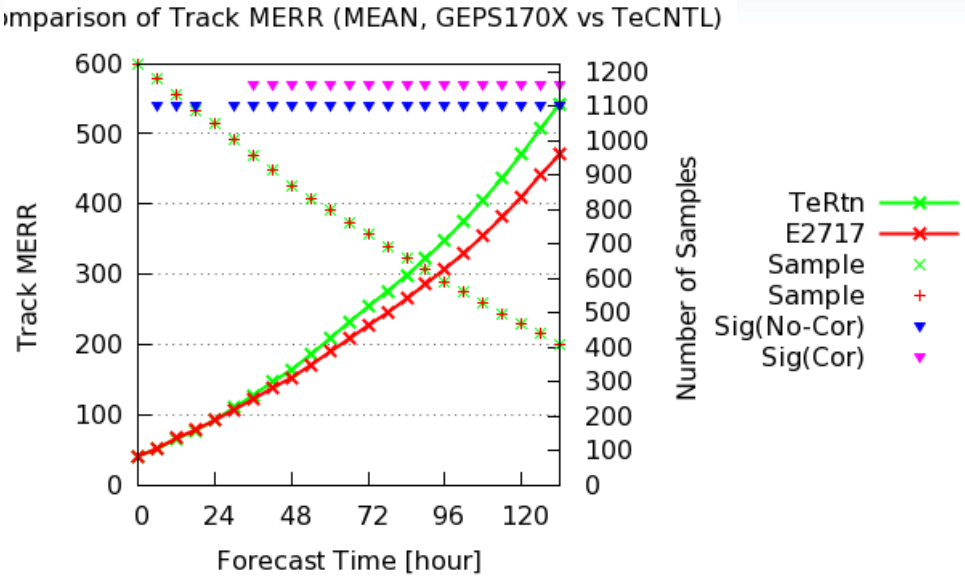
Red : New GEPS
Green : Old TEPS

Control member



Better

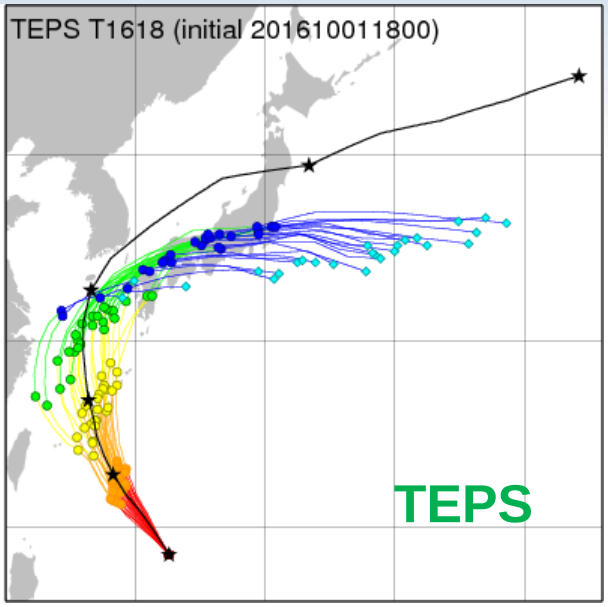
Ensemble mean

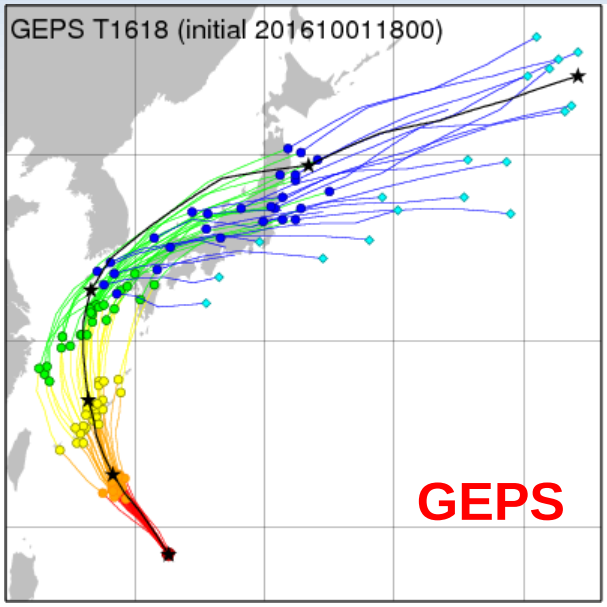


Large improvement was confirmed !

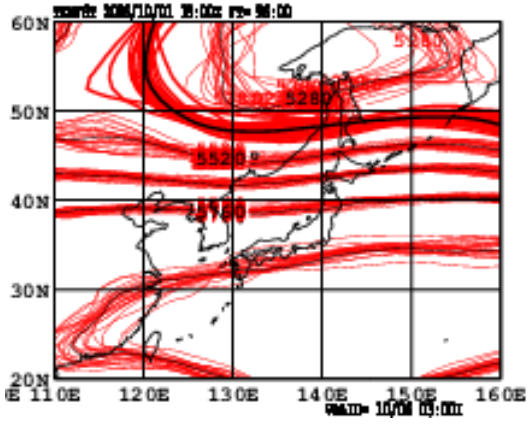
Mean TC position errors (in km) of control member (left) and ensemble mean (right) forecasts for T1503 to T1618.
“+” correspond to the vertical axis on the right, which represents the number of verification samples.

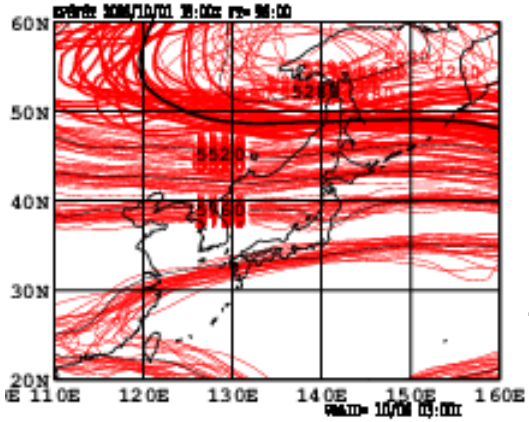
Case study: Typhoon CHABA (T1618)
(2016/10/01/18UTC init)



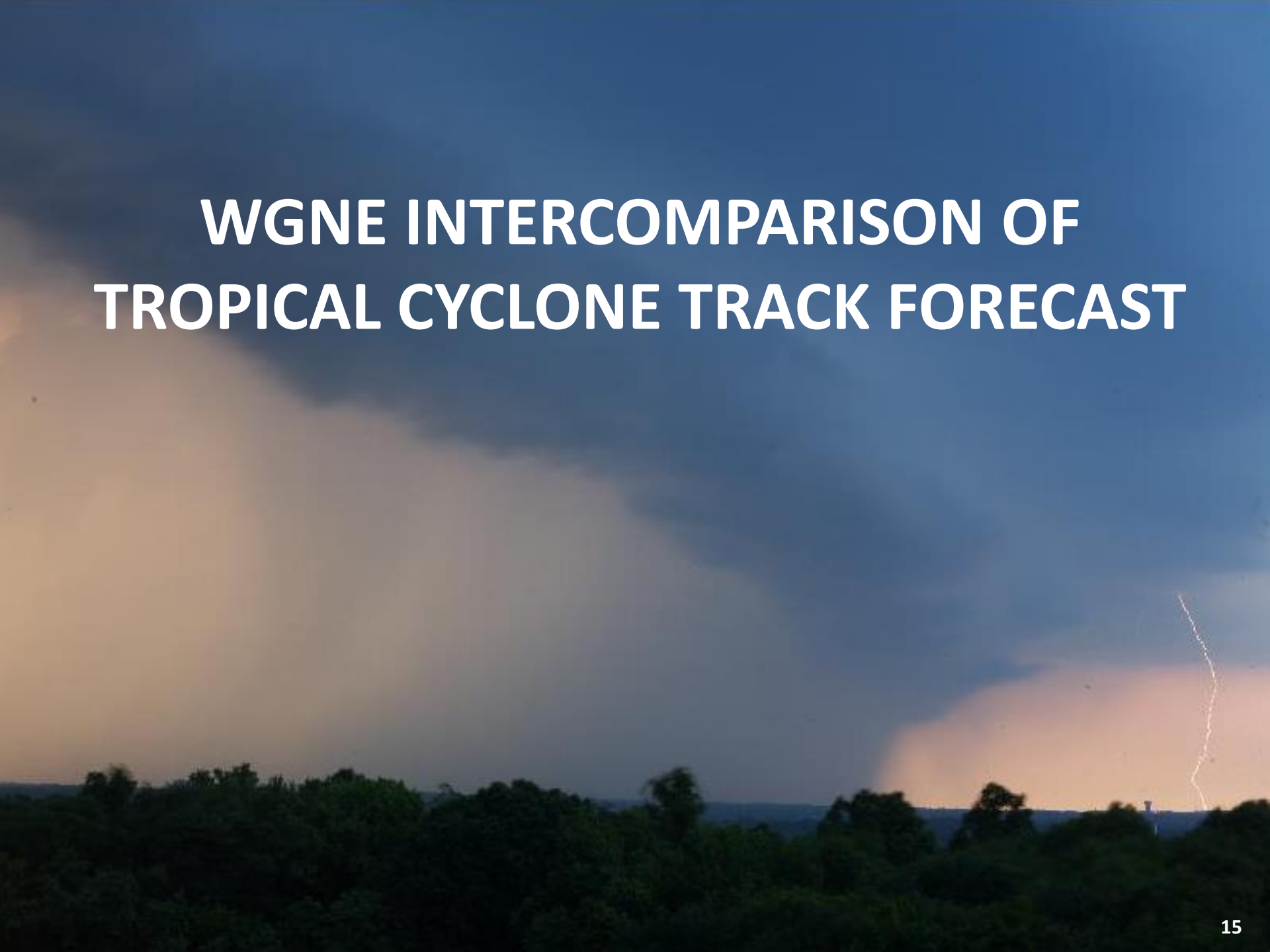


The upgrade of the forecast model reduced the TC track error of control member forecast.
The introduction of LETKF initial perturbations and SST perturbations enlarged the ensemble spread, which contributed to better capture of actual TC track.





Z500 spaghetti diagram (FT+96)



WGNE INTERCOMPARISON OF TROPICAL CYCLONE TRACK FORECAST

JSC/CAS Working Group on Numerical Experimentation (WGNE)

- WGNE
  - Jointly established by the WCRP Joint Scientific Committee (JSC) and the WMO Commission for Atmospheric Sciences (CAS), which is responsible for WWRP and GAW
  - Responsibility: fostering the development of atmospheric circulation models for use in weather, climate, water and environmental prediction
  - As part of its contribution to the WGNE, JMA has conducted intercomparison of TC forecasts based on global NWP model output since 1991.
    - A paper titled “WGNE Intercomparison of Tropical Cyclone Forecasts by Operational Global Models: A Quarter-Century and Beyond” (Yamaguchi et al.) was submitted to BAMS.

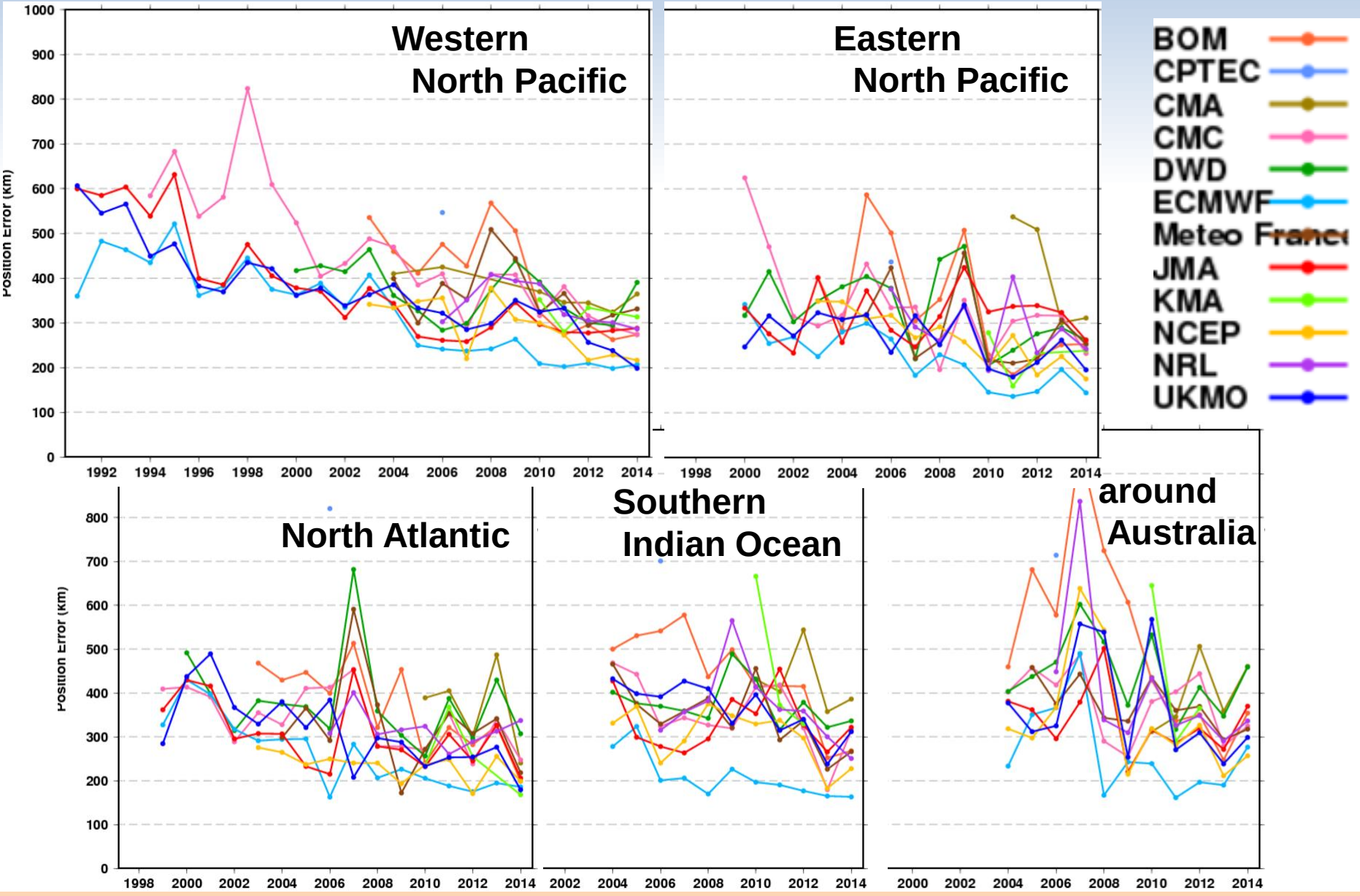
History of the Project

- 1991 : commencement with three centers: ECMWF, UKMO and JMA. The verification area was only western North Pacific.
- 1994 : CMC joined.
- 1999 : Verification for the North Atlantic started.
- 2000 : DWD joined. Verification for the eastern North Pacific started.
- 2002 : Verification for 2 Southern Hemispheric regions, north Indian Ocean and the Central Pacific started.
- 2003 : NCEP and BoM joined. A website for this intercomparison project was launched.
- 2004 : Meteo-France and CMA joined.
- 2006 : CPTEC and NRL joined.
- 2011 : KMA joined. CMA came back.

2015: 11 NWP centers participated in the project.
〔BOM CMA CMC DWD ECMWF JMA KMA France NCEP NRL UKMO 〕

JMA collects forecast data from participating NWP centers, verifies TC track forecasts and reports the verification results at the WGNE meeting every year.

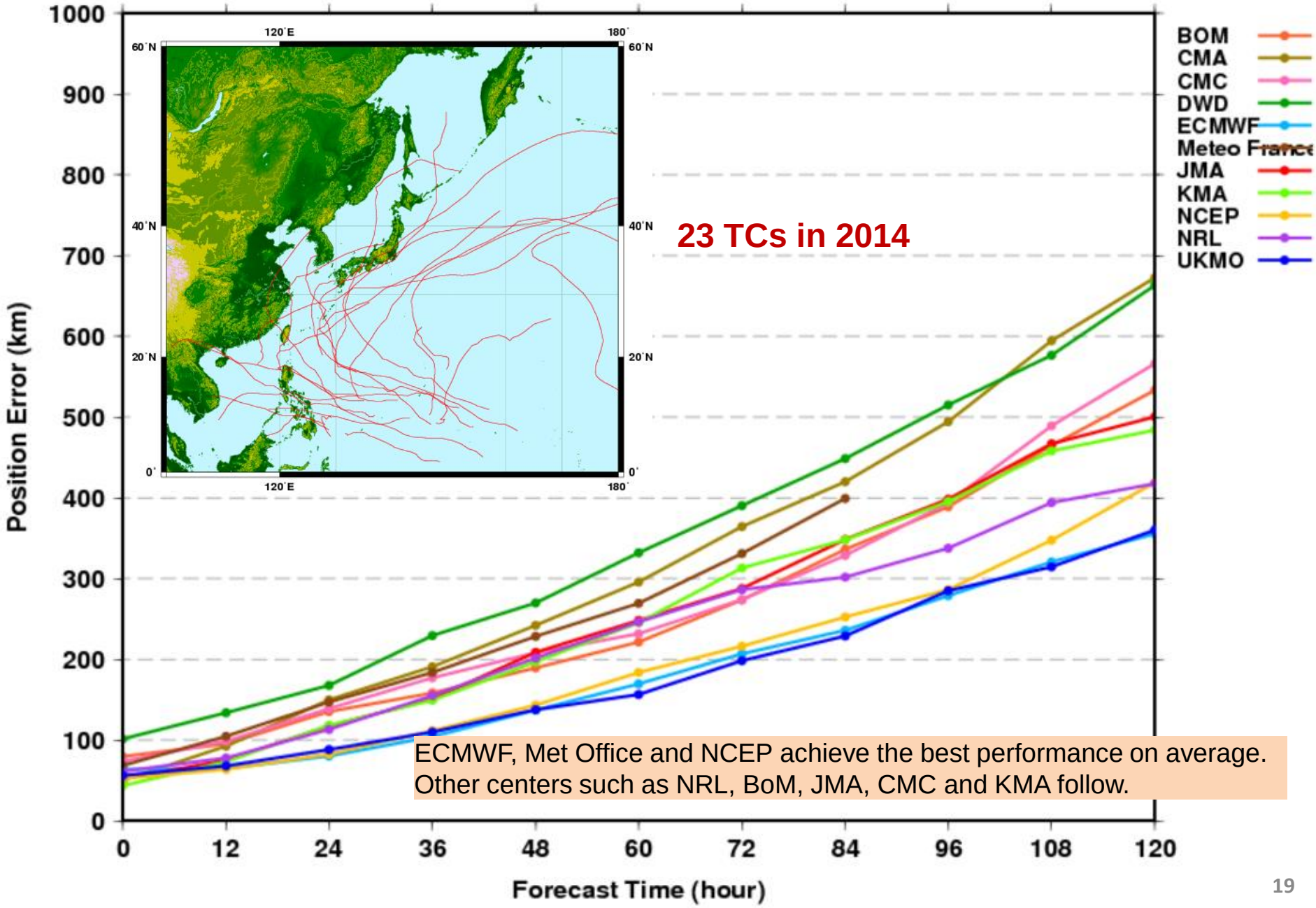
Transition of T+72 position error over decade(s)



Recent improvements of Met Office and NCEP are quite significant in WNP region.

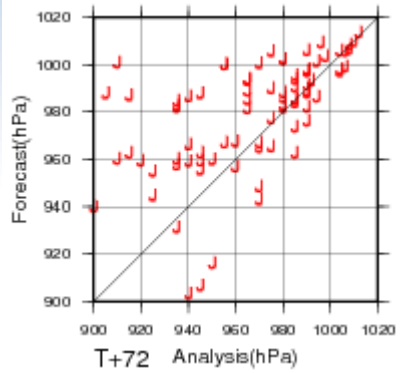
The forecast for TCs in SIO region in 2014 was more difficult than that in 2013 for almost all centers except ECMWF.

Western North-Pacific (WNP) domain Position Error (2014)

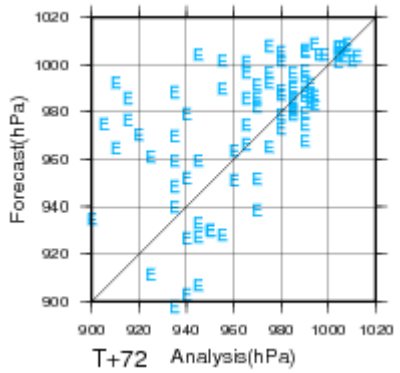


WNP domain Central Pressure scatter diagram (2014)

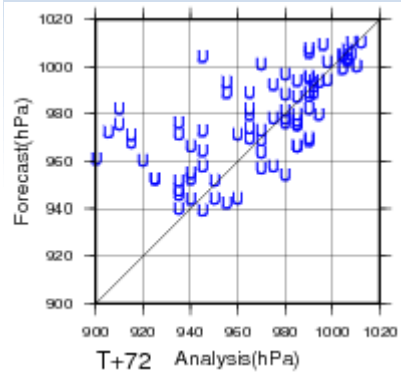
JMA



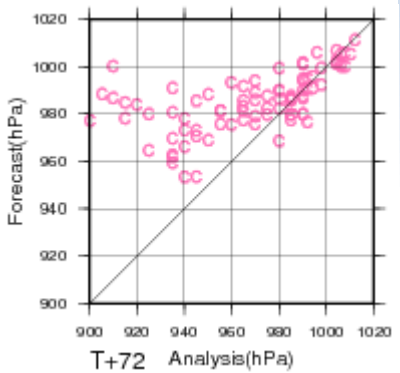
ECMWF



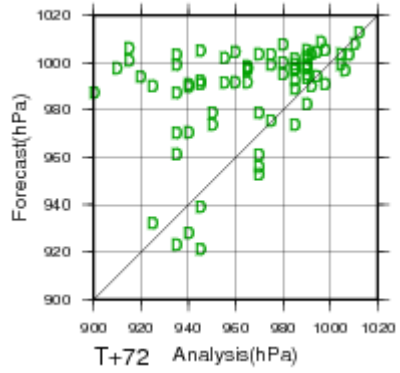
UKMO



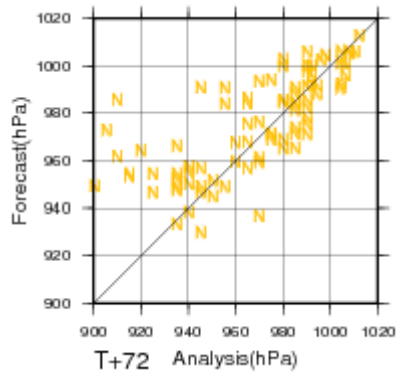
CMC



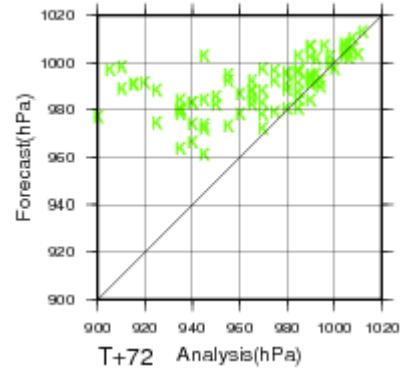
DWD



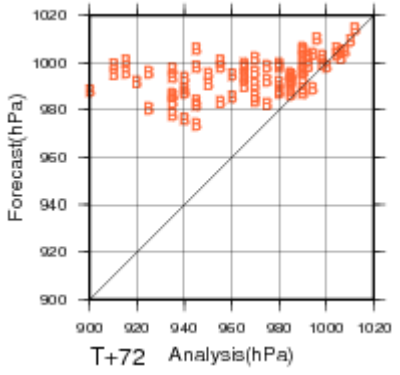
NCEP



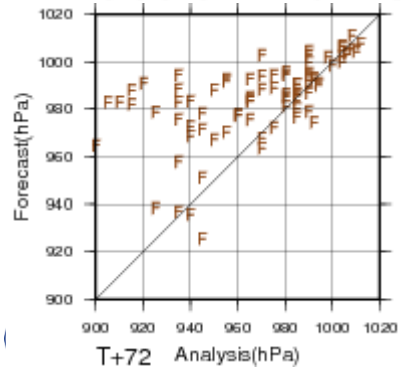
KMA



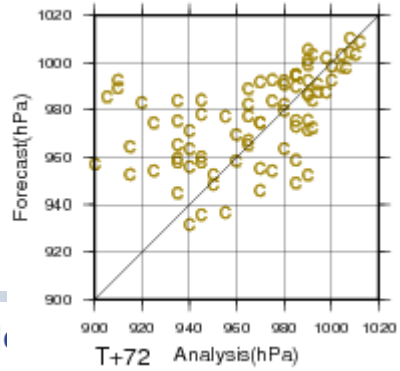
BOM



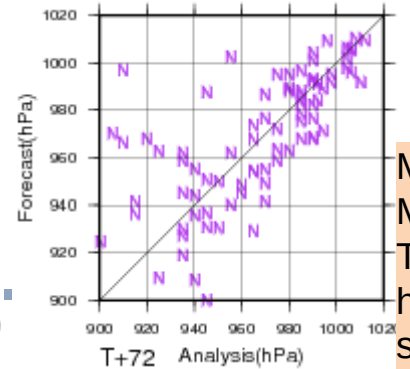
Meteo France



CMA



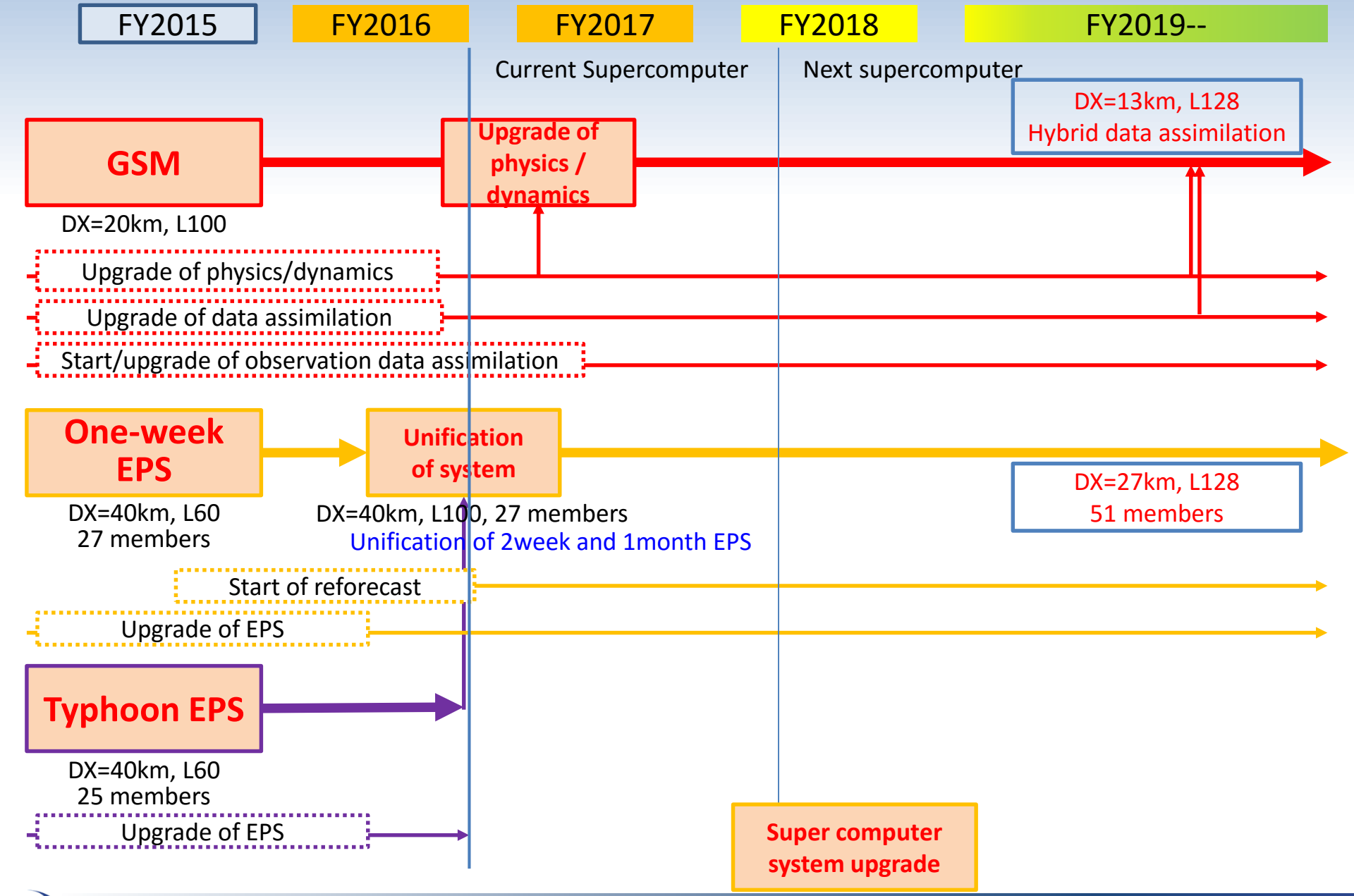
NRL



Scatter diagram of central pressure at FT+72. Y-axis represents central pressure of forecast and X-axis does that of analysis. Unit: hPa

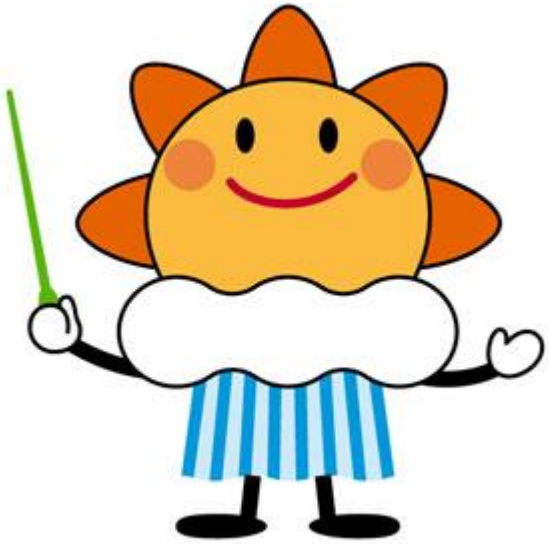
Met Office, CMC, DWD, KMA, BoM and Meteo France predict relatively shallow TCs, while JMA, ECMWF, NCEP and NRL has small bias in deep TC though the spread is not small.

FUTURE PLAN AND SUMMARY


FY2015
FY2016
FY2017
FY2018
FY2019--
Current Supercomputer
Next supercomputer
GSM
DX=20km, L100
Upgrade of physics / dynamics
DX=13km, L128
Hybrid data assimilation
Upgrade of physics/dynamics
Upgrade of data assimilation
Start/upgrade of observation data assimilation
One-week EPS
DX=40km, L60
27 members
Unification of system
DX=40km, L100, 27 members
Unification of 2week and 1month EPS
DX=27km, L128
51 members
Start of reforecast
Upgrade of EPS
Typhoon EPS
DX=40km, L60
25 members
Upgrade of EPS
Super computer system upgrade

Summary

- JMA has been continuously developing its NWP system to reduce TC track forecast error.
- In March 2014, JMA started assimilation of Himawari-8 AMV, CSR data and GPM/GMI data and upgraded GSM.
  - All upgrades contribute to the improvement of TC track forecasts.
- In January 2017, JMA started operation of Global EPS.
  - One-week EPS and Typhoon EPS were unified and renamed to Global EPS.
  - The model was upgraded and initial perturbations from LETKF and perturbations to sea surface temperature were introduced.
  - Substantial improvements are seen in TC track forecast.
- JMA has led the inter-comparison study project of TC track forecast verification at the WGNE since 1991, in which many operational NWP Centers participate.
  - The knowledge from the project fosters the development of the NWP systems at each center.
  - The results of TC verification show remarkable improvements of the operational Global NWP models in all the participating centers year by year.

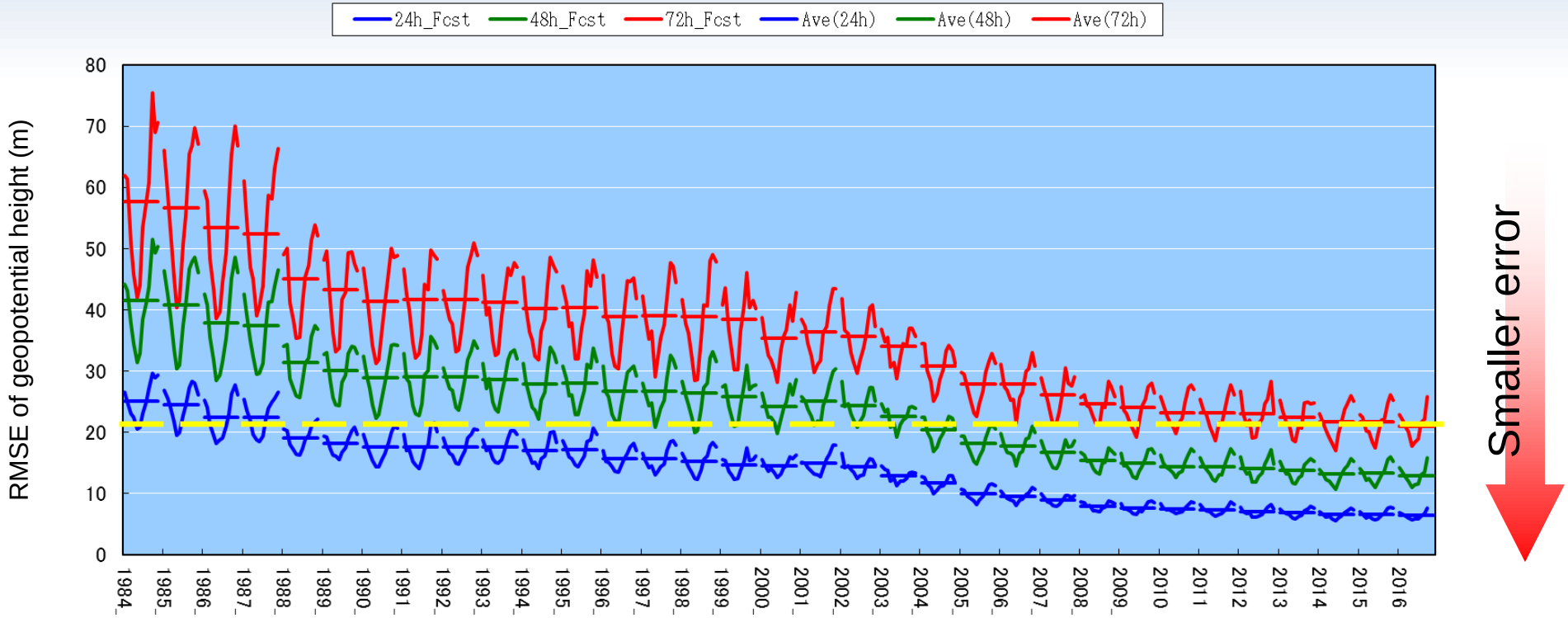


Thank you for your attention.

BACKUP SLIDES

Verification score of GSM

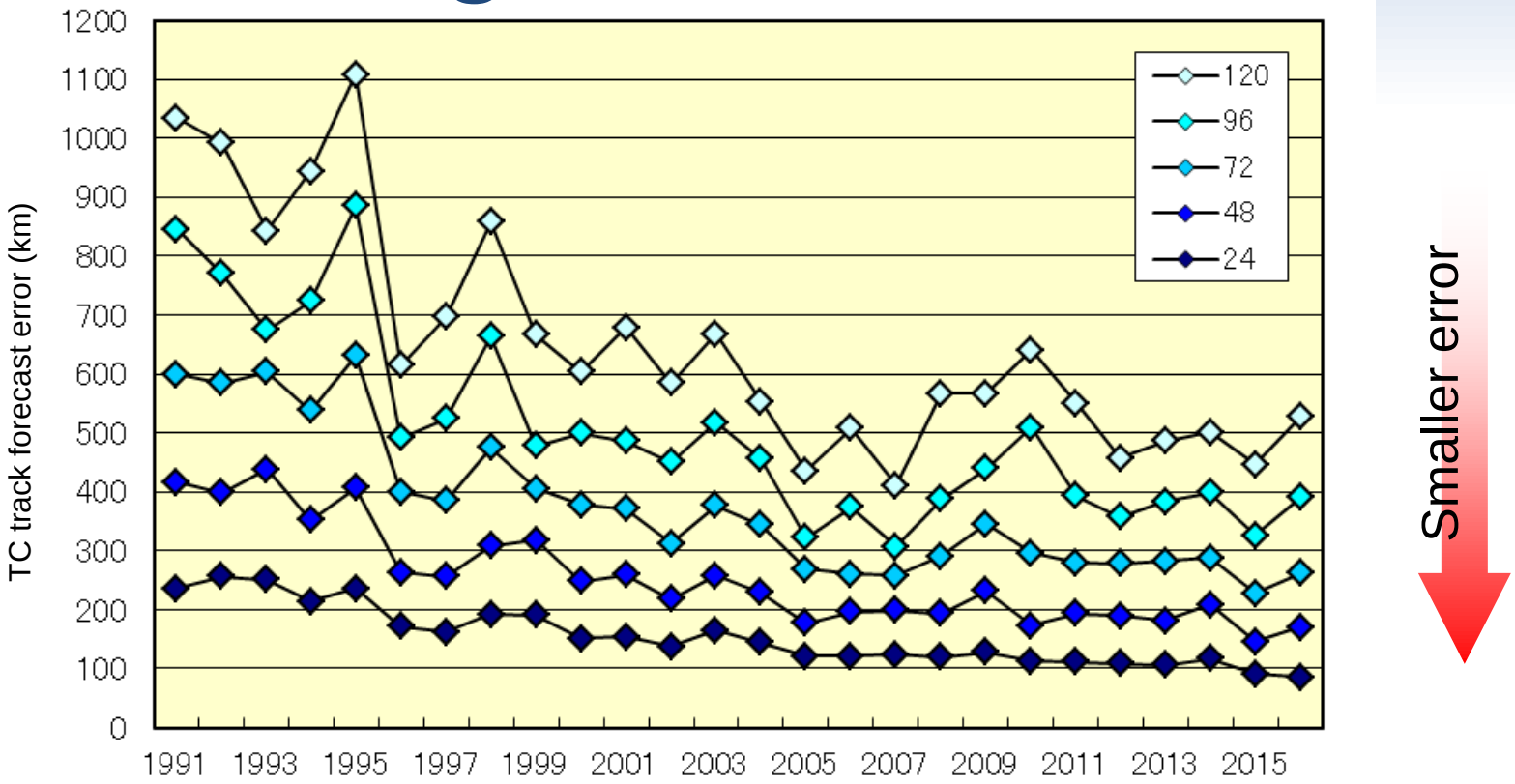
1-day forecast **2**-day forecast **3**-day forecast



RMSE of 500 hPa geopotential height in Northern Hemisphere (20-90N)

The accuracy of 3-day forecast in 2016 compares with that of 1-day forecast in 1980's.

Tropical cyclone track forecast error of global model

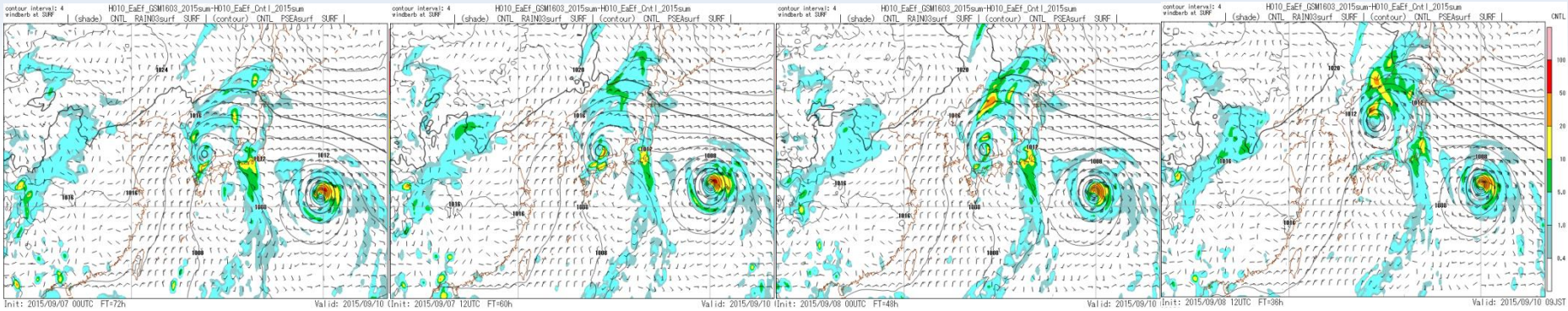


As a result of continuous development, typhoon position error has been continuously decreasing.
The accuracy of 120 hr forecast in 2016 compares with that of 72 hr forecast in early 1990's.

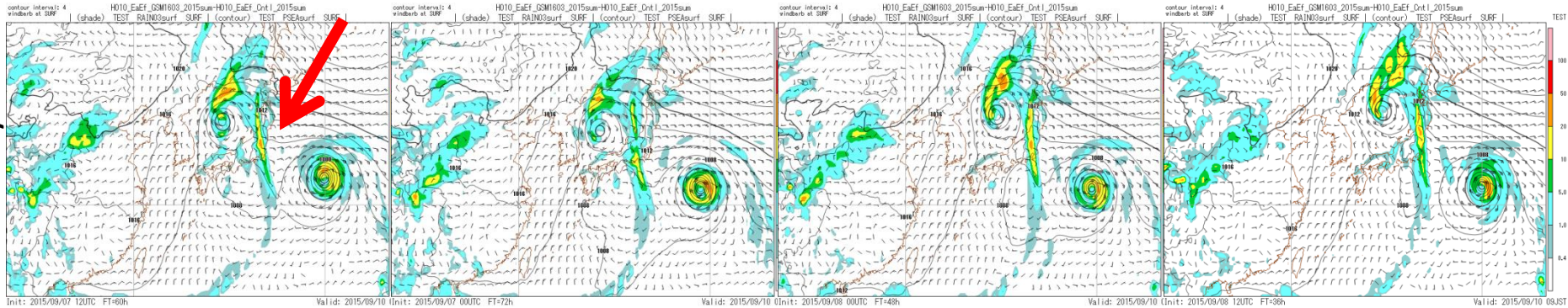
Improvement in precipitation forecasts （Valid: 09JST 10 Sep. 2015）

T+72 T+60 T+48 T+36

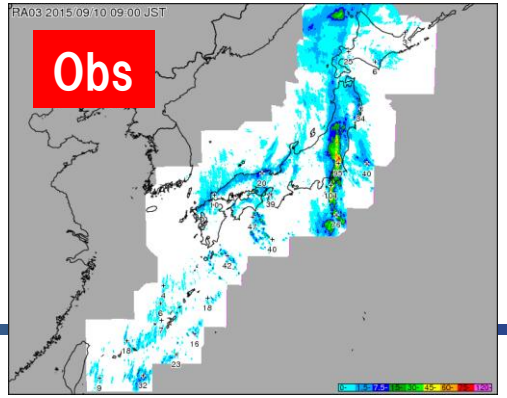
Old system



New system



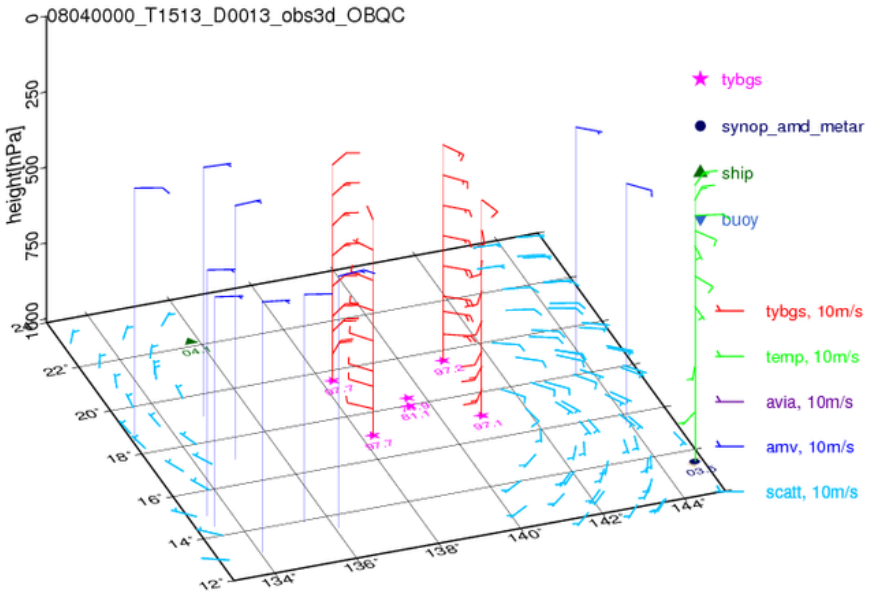
*Better representation of typhoons contributes to improvement in precipitation forecasts over the eastern part of Japan.
*Precipitation and sea level pressure forecasted in the new system are more consistent between different lead times.



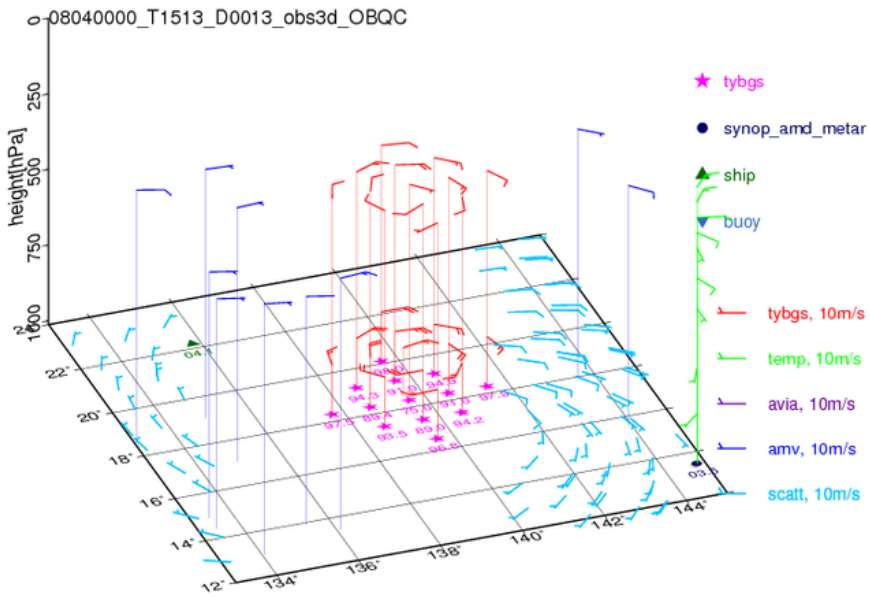
Revision of Typhoon Bogus Configuration

Typhoon Bogus（★:Sea Surface Pressure、Arrow:Winds）

Old Version



New Version



- Position of Sea Surface Pressure Data

（Old）TC centers of FG,
and analyzed TC centers and 4 points on its circumference of a radius of 200km.
（New）Analyzed TC centers and 1 point per every 100km grid box in the circle of a radius of 200km.
（※when the distance between TC centers between FG and analyzed TC ≤ 120km）

- Position of Upper-level Winds

（Old）9 Pressure Levels at 1000,925,900,850,700,600,500,400 and 300 hPa
（New）2 Pressure Levels at 850 and 300 hPa

Making typhoon bogus

Axisymmetric component:

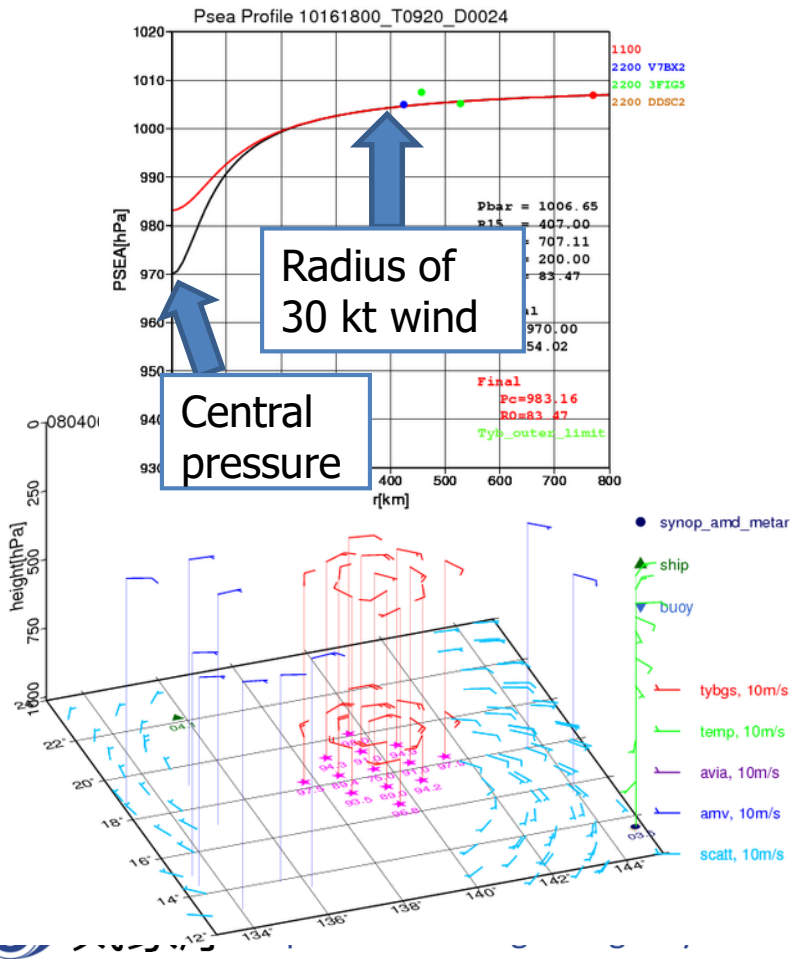
Based on analyzed position, central pressure and radius of 30 kt wind, a symmetric field is made.

Asymmetric component: retrived from the first guess

Add these two components

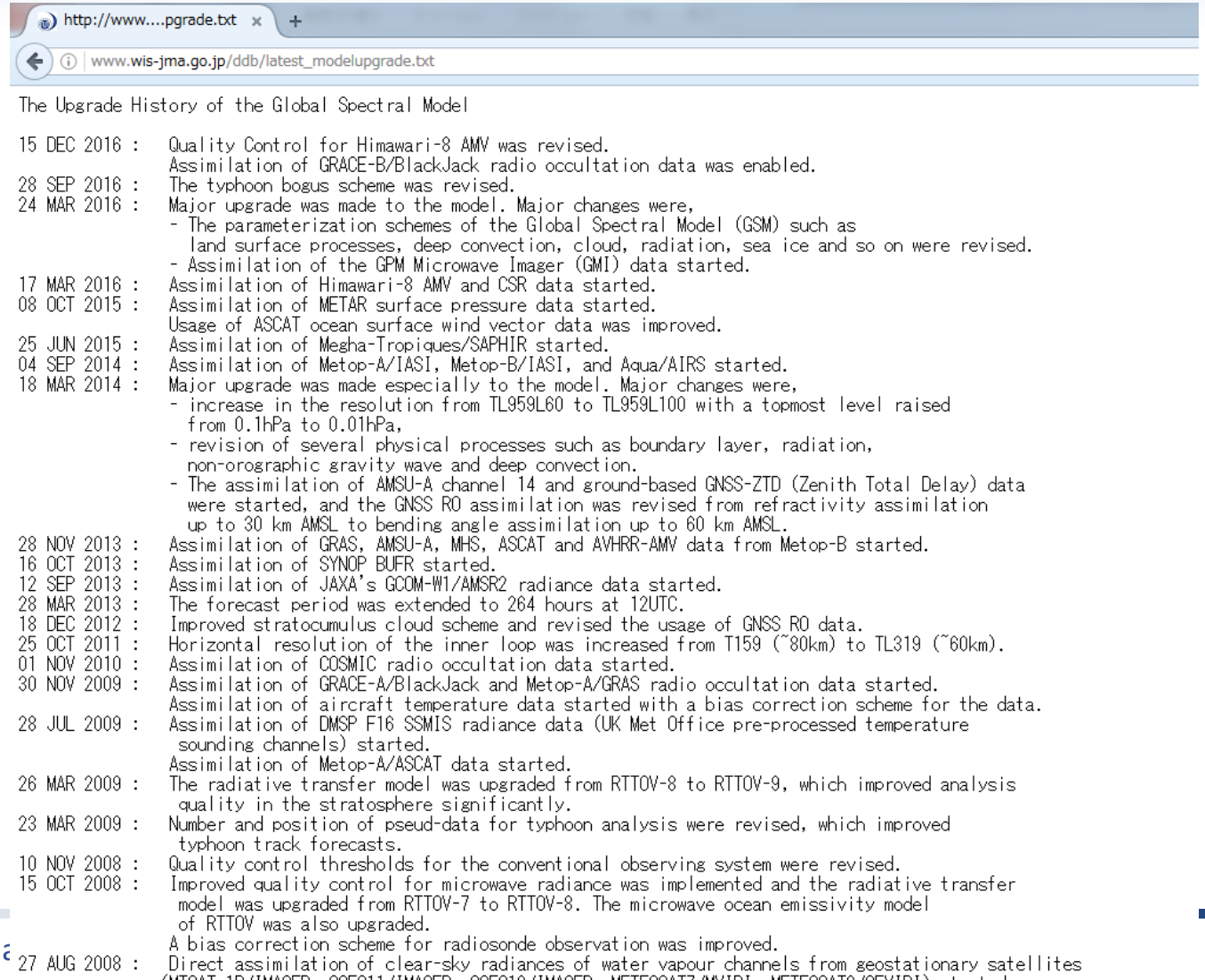
Pick up pseudo-observation data from the calculated 3D field for points around the typhoon center.

This pseudo-observational bogus data are put into 4D-Var analysis as Psea and upper observational data (1000～300 hPa)



The update history of the high-resolution GSM is within easy access of the following website.

http://www.wis-jma.go.jp/ddb/latest_modelupgrade.txt



http://www....pgrade.txt

www.wis-jma.go.jp/ddb/latest_modelupgrade.txt

The Upgrade History of the Global Spectral Model

15 DEC 2016 : Quality Control for Himawari-8 AMV was revised.
Assimilation of GRACE-B/BlackJack radio occultation data was enabled.
28 SEP 2016 : The typhoon bogus scheme was revised.
24 MAR 2016 : Major upgrade was made to the model. Major changes were,
- The parameterization schemes of the Global Spectral Model (GSM) such as land surface processes, deep convection, cloud, radiation, sea ice and so on were revised.
- Assimilation of the GPM Microwave Imager (GMI) data started.
17 MAR 2016 : Assimilation of Himawari-8 AMV and CSR data started.
08 OCT 2015 : Assimilation of METAR surface pressure data started.
Usage of ASCAT ocean surface wind vector data was improved.
25 JUN 2015 : Assimilation of Megha-Tropiques/SAPHIR started.
04 SEP 2014 : Assimilation of Metop-A/IASI, Metop-B/IASI, and Aqua/AIRS started.
18 MAR 2014 : Major upgrade was made especially to the model. Major changes were,
- increase in the resolution from TL959L60 to TL959L100 with a topmost level raised from 0.1hPa to 0.01hPa,
- revision of several physical processes such as boundary layer, radiation, non-orographic gravity wave and deep convection.
- The assimilation of AMSU-A channel 14 and ground-based GNSS-ZTD (Zenith Total Delay) data were started, and the GNSS RO assimilation was revised from refractivity assimilation up to 30 km AMSL to bending angle assimilation up to 60 km AMSL.
28 NOV 2013 : Assimilation of GRAS, AMSU-A, MHS, ASCAT and AVHRR-AMV data from Metop-B started.
16 OCT 2013 : Assimilation of SYNOP BUFR started.
12 SEP 2013 : Assimilation of JAXA's GCOM-W1/AMSR2 radiance data started.
28 MAR 2013 : The forecast period was extended to 264 hours at 12UTC.
18 DEC 2012 : Improved stratocumulus cloud scheme and revised the usage of GNSS RO data.
25 OCT 2011 : Horizontal resolution of the inner loop was increased from T159 (~80km) to TL319 (~60km).
01 NOV 2010 : Assimilation of COSMIC radio occultation data started.
30 NOV 2009 : Assimilation of GRACE-A/BlackJack and Metop-A/GRAS radio occultation data started.
Assimilation of aircraft temperature data started with a bias correction scheme for the data.
28 JUL 2009 : Assimilation of DMSP F16 SSMIS radiance data (UK Met Office pre-processed temperature sounding channels) started.
Assimilation of Metop-A/ASCAT data started.
26 MAR 2009 : The radiative transfer model was upgraded from RTTOV-8 to RTTOV-9, which improved analysis quality in the stratosphere significantly.
23 MAR 2009 : Number and position of pseud-data for typhoon analysis were revised, which improved typhoon track forecasts.
10 NOV 2008 : Quality control thresholds for the conventional observing system were revised.
15 OCT 2008 : Improved quality control for microwave radiance was implemented and the radiative transfer model was upgraded from RTTOV-7 to RTTOV-8. The microwave ocean emissivity model of RTTOV was also upgraded.
A bias correction scheme for radiosonde observation was improved.
27 AUG 2008 : Direct assimilation of clear-sky radiances of water vapour channels from geostationary satellites

TC Verification for 2014 season

TC tracks on 2014 season

Northern-Hemisphere [2014/01/01 to 2014/12/31]

Southern-Hemisphere [2013/09/01 to 2014/08/31]

Number of TCs , [best-track data provider]

23 western North-Pacific [RSMC Tokyo]

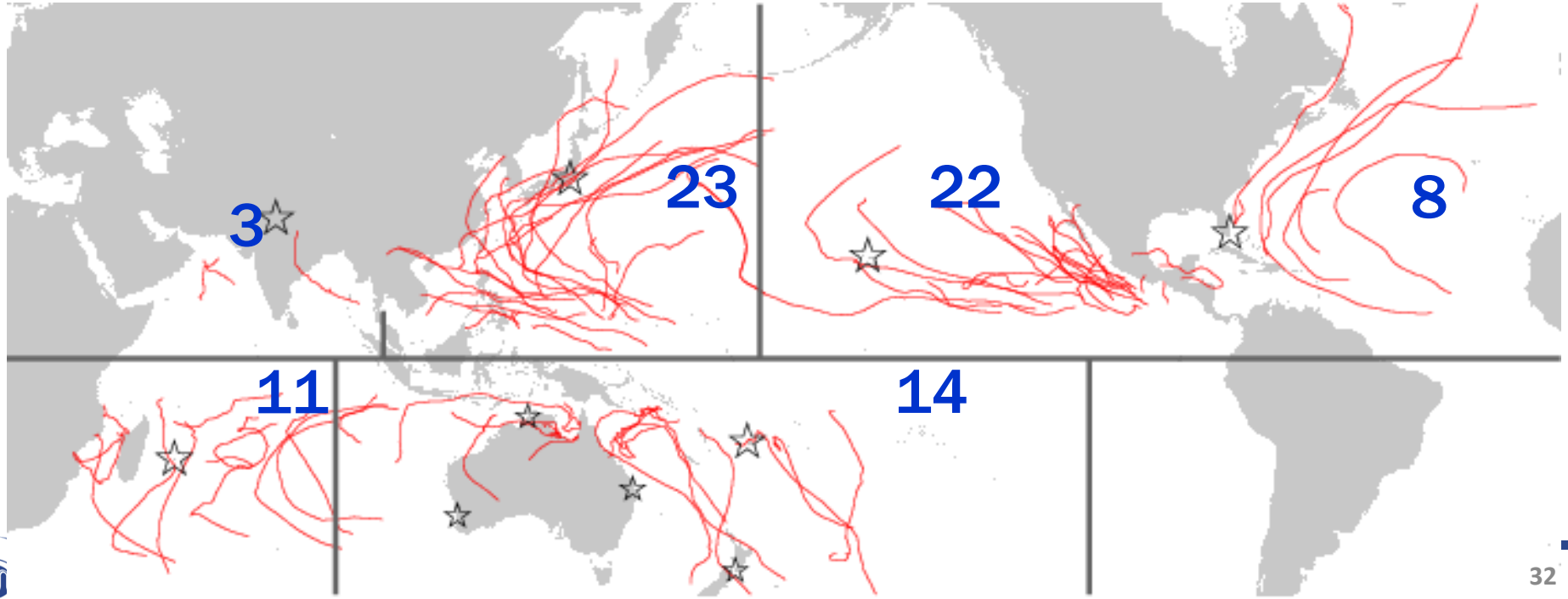
22 eastern North-Pacific (including Central-Pacific) [RSMC Miami, Honolulu]

8 North Atlantic [RSMC Miami]

3 north Indian-Ocean [RSMC New-Delhi]

11 south Indian-Ocean [RSMC La-Reunion]

14 around Australia [RSMC Nadi and 4 TCWCs]



Method of TC verification using MSLP

TCs to be verified

TCs which intensity reached tropical storm (TS) with the maximum sustained wind of 34 knots or stronger are set as targets for this verification. The tropical depression (TD) stage of the targeted TCs is also included in this verification. However, the TCs which stayed at TD level all through their life are excluded.

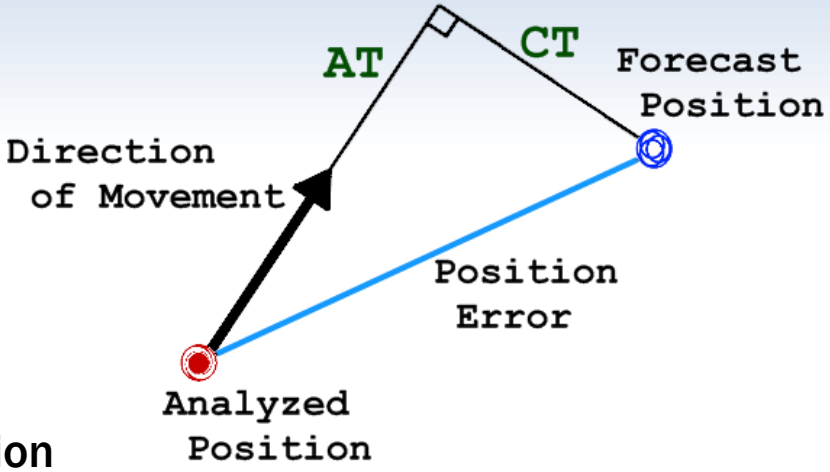
1. Tracking Method

local pressure minimum;

a) First position (FT +0hr) : search from the best track position
b) Second position (FT +6hr) : search from the first position
c) Third and after (FT +12hr~) : search from estimated position from the latest two positions

(all position searched within 500km radius)

2. Verification Method



- **Position Error〔km〕**

  The distance between
  the best-track (analyzed) position
  and the forecast position.

- **Along Track – Cross Track bias**

  AT(along-track)-bias : The bias in the direction of TC movement

  CT(cross-track)-bias : The bias in the rectangular direction of TC movement

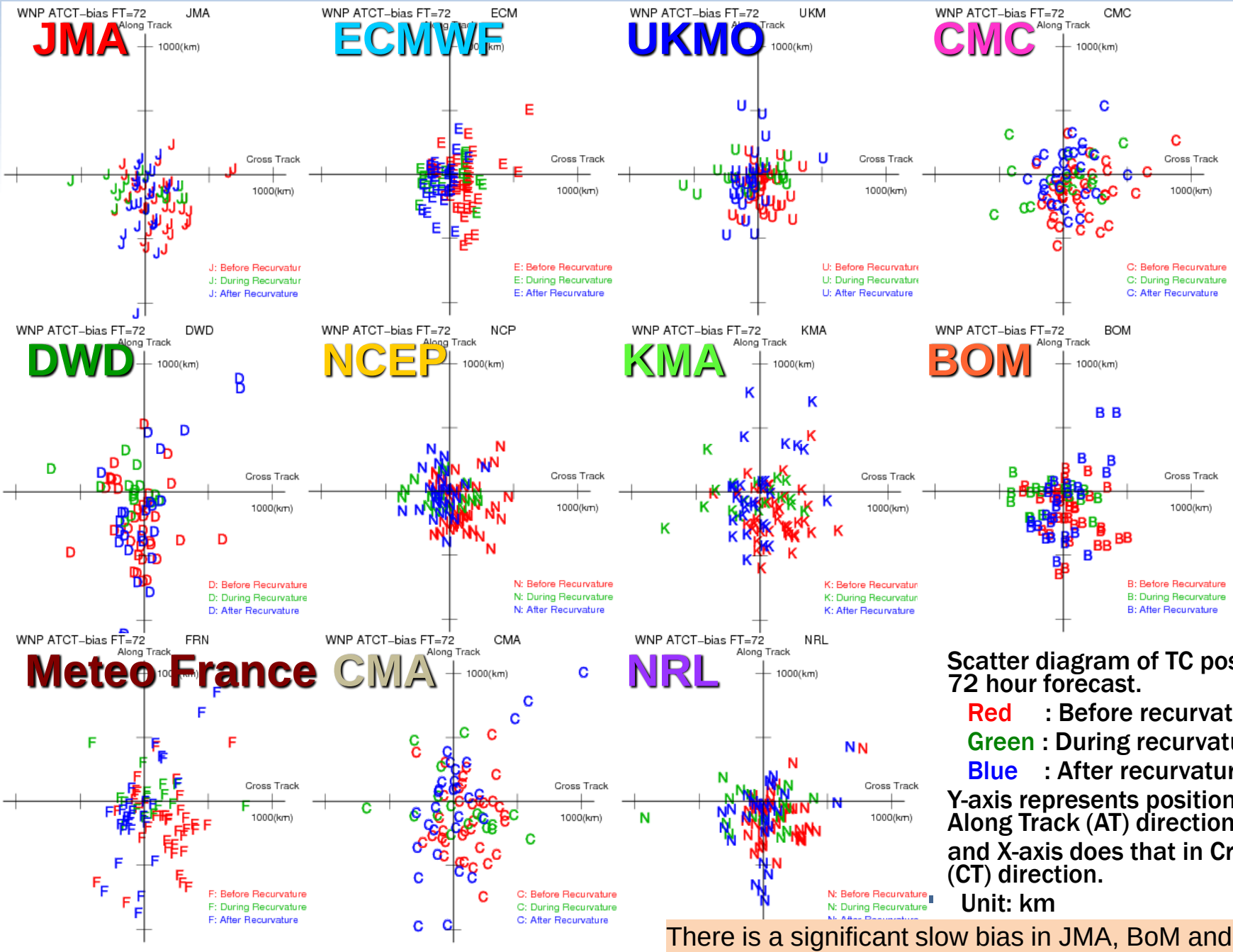
- **Detection Rate**

  Detection Rate (t) = A(t)/ B(t)

  A(t) : *The number of forecast events in which a TC is analyzed at forecast time t on the condition that a NWP model continuously expresses the TC until the forecast time t.*

  B(t) : *The number of forecast events in which a TC is analyzed at forecast time t.*

(a) WNP domain AT-CT bias map (FT +72)



Scatter diagram of TC positions at 72 hour forecast.

Red : Before recurvature

Green : During recurvature

Blue : After recurvature

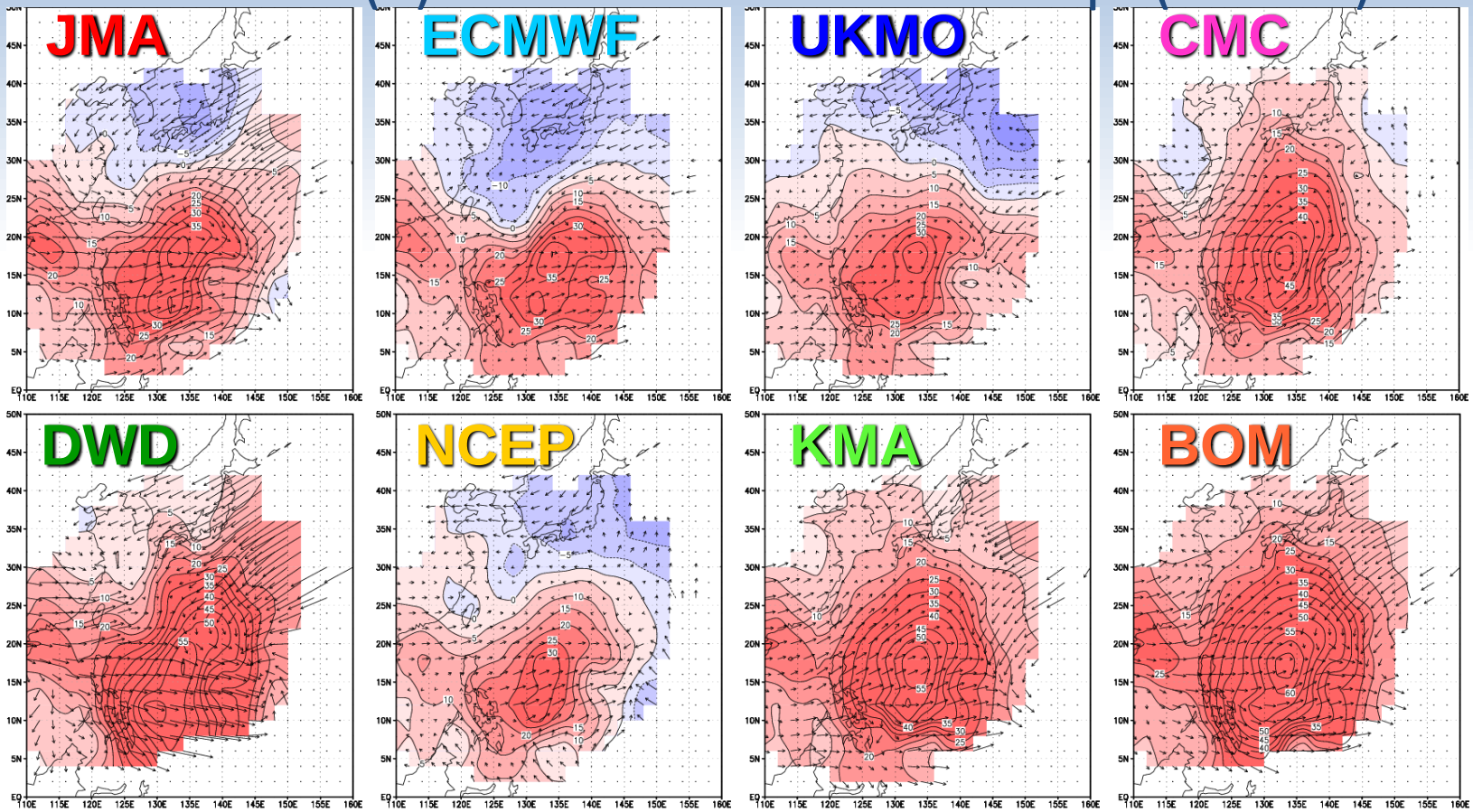
Y-axis represents position errors in Along Track (AT) direction

and X-axis does that in Cross Track (CT) direction.

Unit: km

There is a significant slow bias in JMA, BoM and NRL.

(a) WNP domain Error Map (FT +72)



Forecast position

Analysis position

Error map of central pressure and position at 72 hour forecast.
Color: Central pressure error
Units: hPa
(Red: forecast is shallow.
Blue: forecast is deep)
Arrow: average position error

All models failed to predict deep TCs around the east of Philippine and the east of Mariana Islands.