



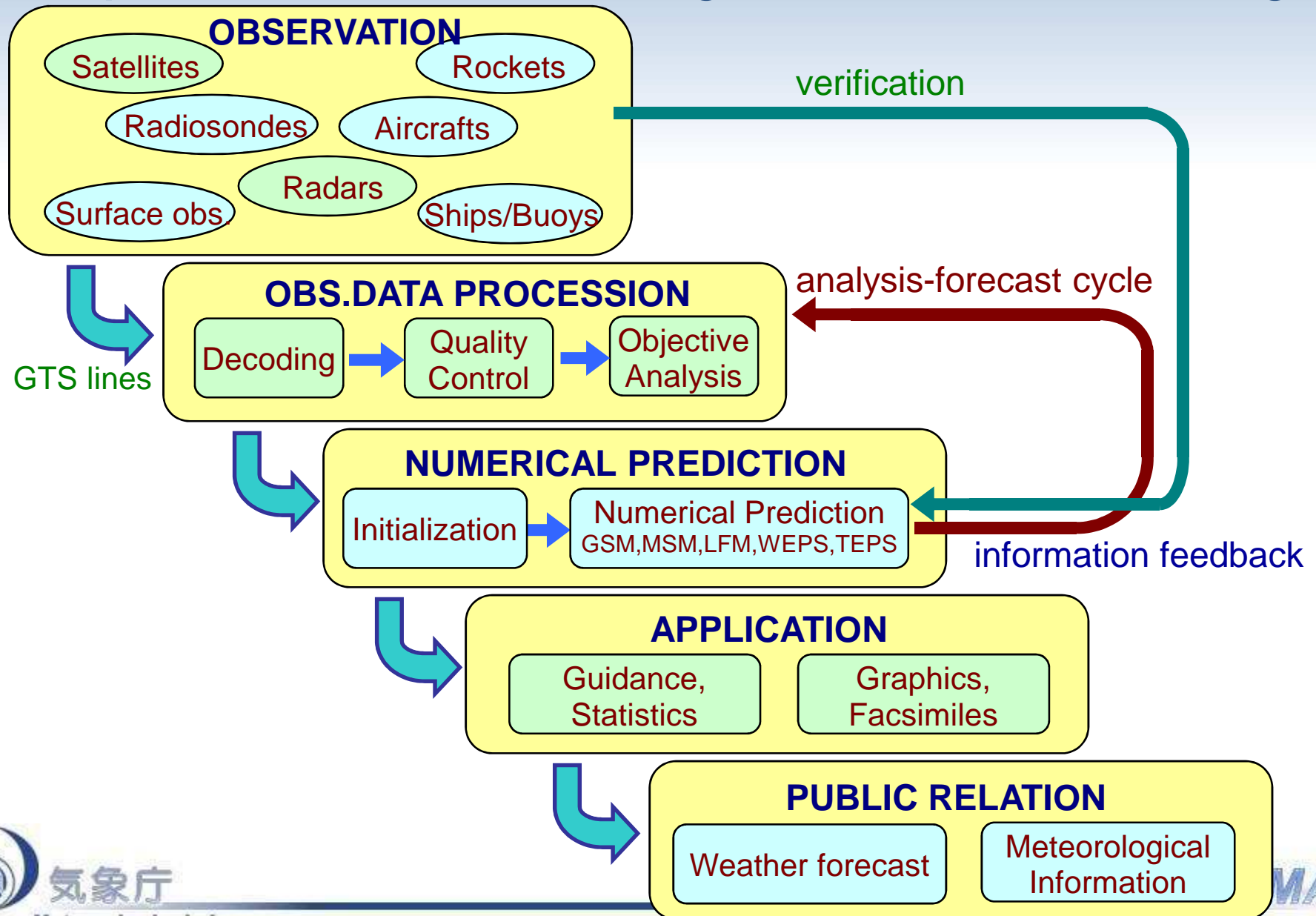
Recent Developments of JMA Operational NWP Systems and WGNE Intercomparison of Tropical Cyclone Track Forecast

Masayuki Nakagawa and colleagues at JMA
Numerical Prediction Division
Japan Meteorological Agency

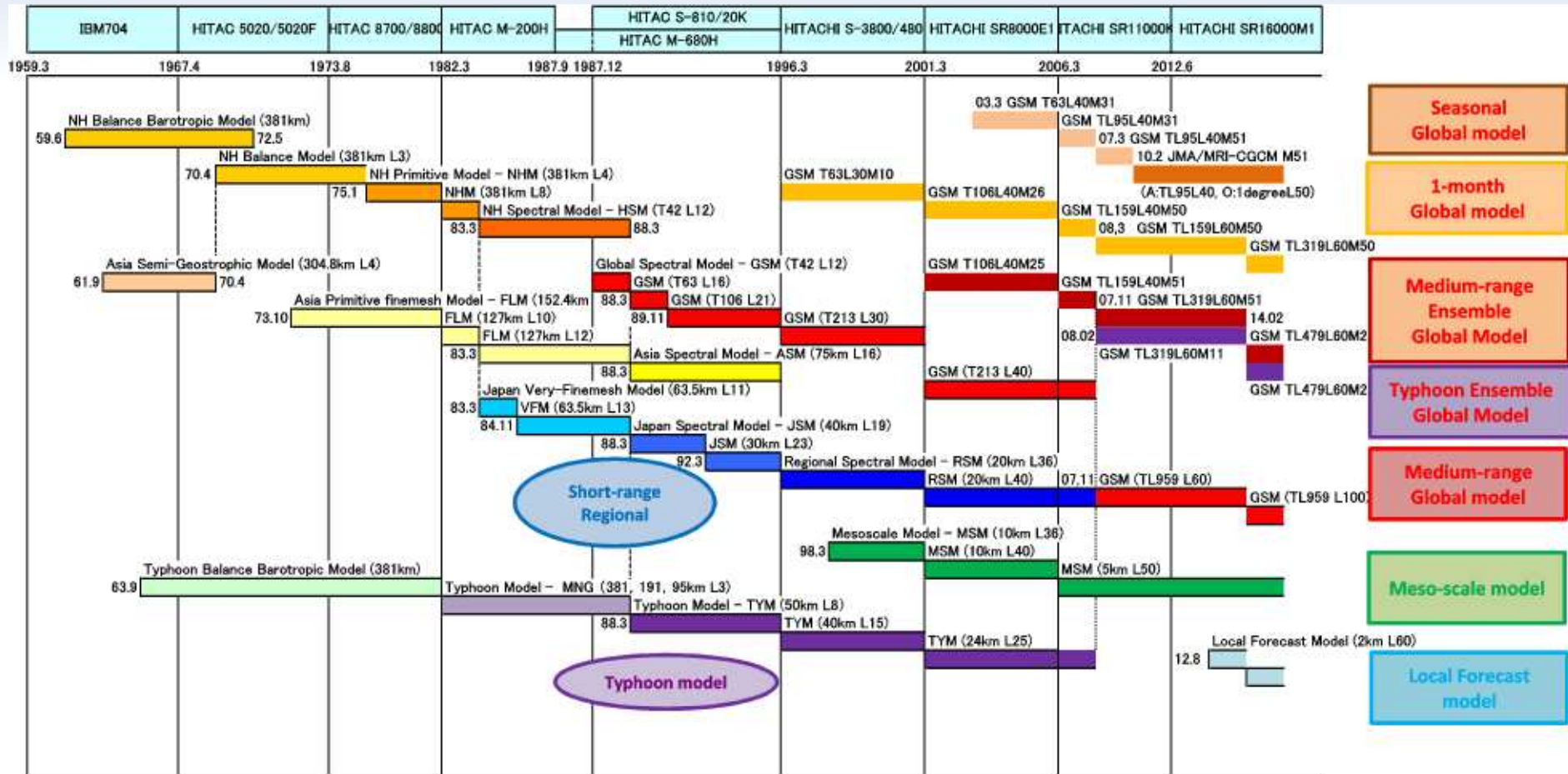
RECENT DEVELOPMENTS OF JMA OPERATIONAL NWP SYSTEMS



Sequence of Meteorological Data Processing

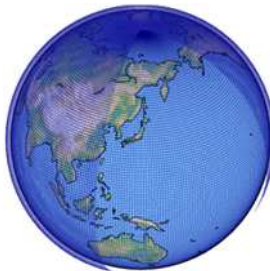





History of operational NWP models at JMA



JMA has been actively developing numerical weather prediction (NWP) systems since the commencement of operational numerical prediction in 1959.

Current NWP models of NPD/JMA

	Global Spectral Model GSM	Meso-Scale Model MSM	Local Forecast Model LFM	One-week Ensemble WEPS	Typhoon Ensemble TEPS
Objectives	Short- and Medium-range forecast	Disaster reduction Aviation forecast	Aviation forecast Disaster reduction	One-week forecast	Typhoon forecast
Forecast domain	Global 	Japan and its surroundings (4080km x 3300km) 	Japan and its surroundings (3160km x 2600km) 	Global 	
Horizontal resolution	TL959(0.1875 deg)	5km	2km	New! TL479(0.375 deg)	
Vertical levels / Top	60 → 100 0.1 → 0.01 hPa	50 21.8km	60 20.2km	60 0.1 hPa	
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 hours (00, 12 UTC) 27 members	132 hours (00, 06, 12, 18 UTC) 25 members
Initial Condition	Global Analysis (4D-Var)	Meso-scale Analysis (4D-Var)	Local Analysis (3D-Var)	Global Analysis with ensemble perturbations (SV)	

Data assimilation systems of NPD/JMA

	Global Analysis (GA)	Meso-scale Analysis (MA)	Local Analysis (LA)
Analysis scheme	4D-Var		3D-Var
Analysis time	00, 06, 12, 18 UTC	00, 03, 06, 09, 12, 15, 18, 21 UTC	hourly
Data cut-off time	2 hours 20 minutes [Early Analysis] 11 hours 50 minutes (00, 12 UTC) 7 hours 50 minutes (06, 18 UTC) [Cycle Analysis]	50 minutes	30 minutes
Horizontal resolution (inner-model resolution)	TL959 / 0.1875 deg (TL319 / 0.5625 deg)	5 km (15 km)	5km
Vertical levels	60 levels up to 0.1 hPa → 100 levels up to 0.01 hPa	50 levels up to 21.8km	50 levels up to 21.8km
Assimilation window	-3 hours to +3 hours of analysis time	-3 hours to analysis time	-

Coming soon!

Verification score of global model

1-day forecast

2-day forecast

3-day forecast

24h_Fcst

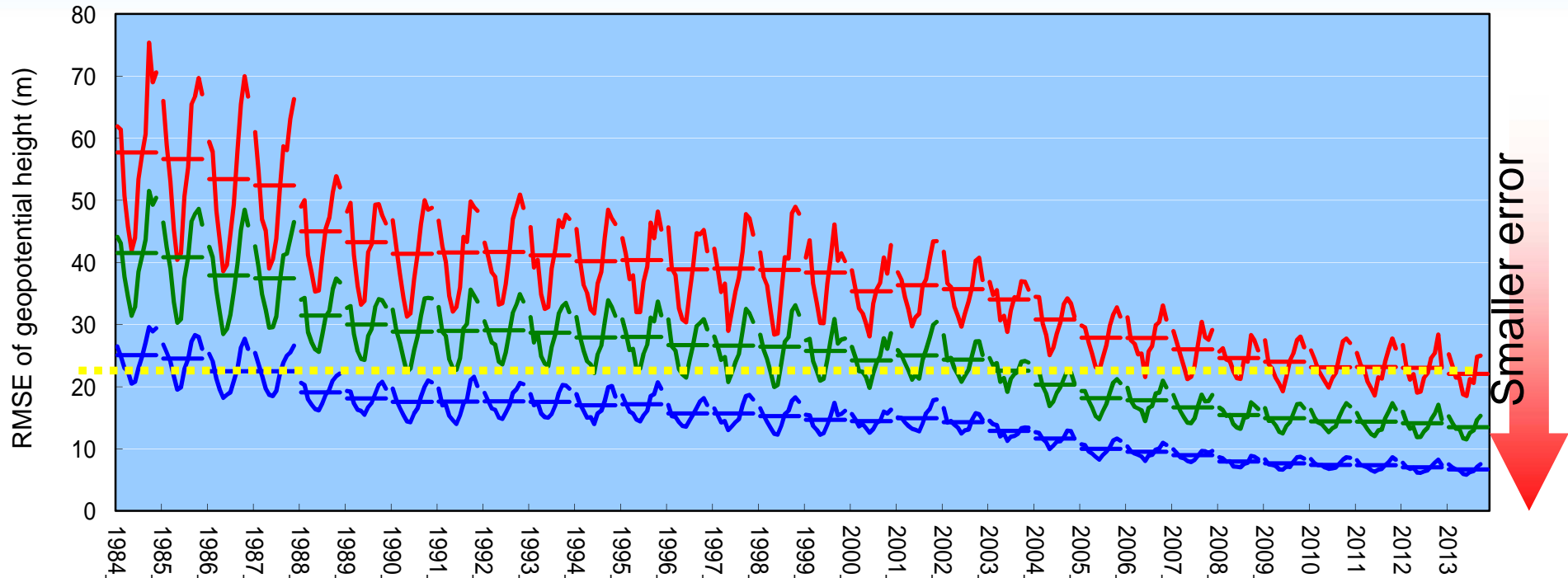
48h_Fcst

72h_Fcst

Ave(24h)

Ave(48h)

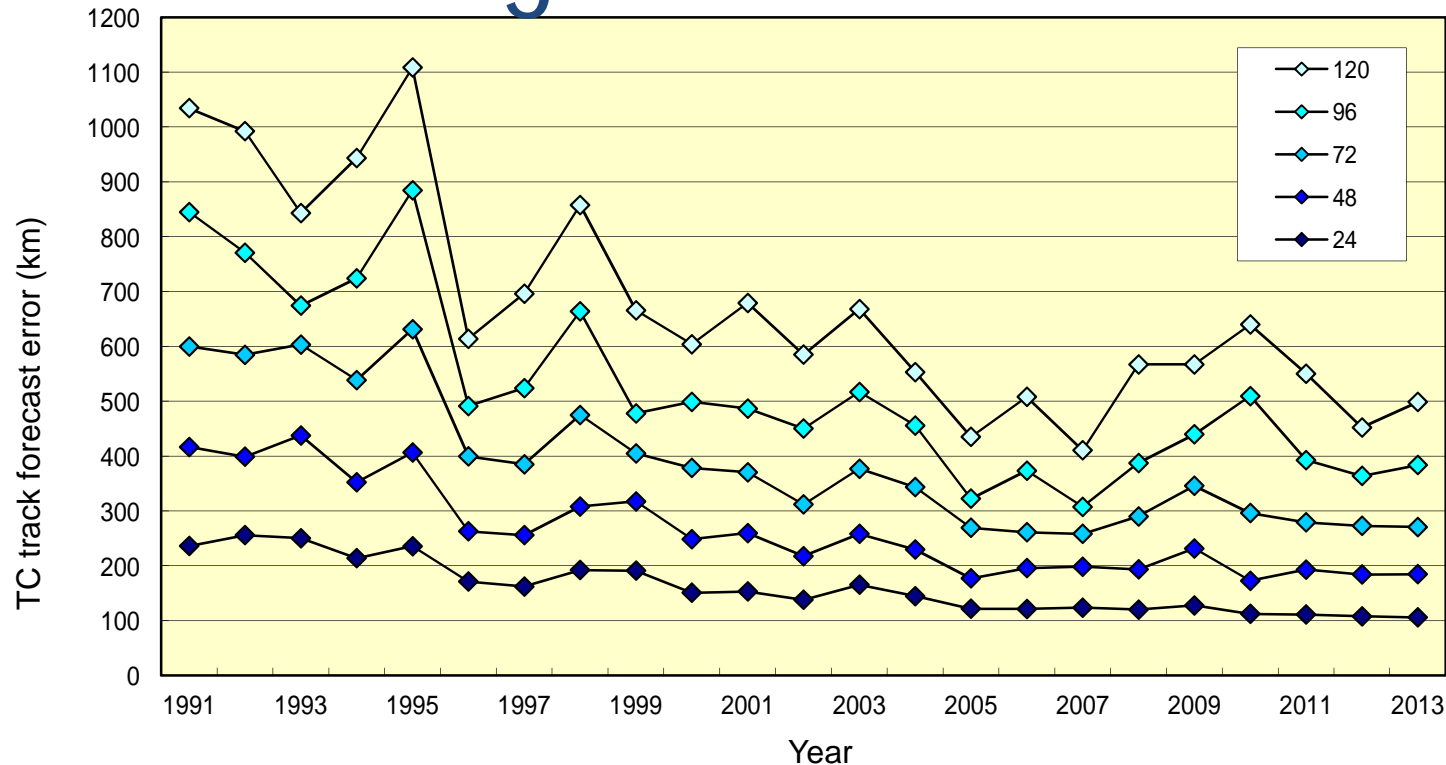
Ave(72h)



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

The accuracy of 3-day forecast in 2013 compares with that of 1-day forecast in 1980's.

Tropical cyclone track forecast error of global model



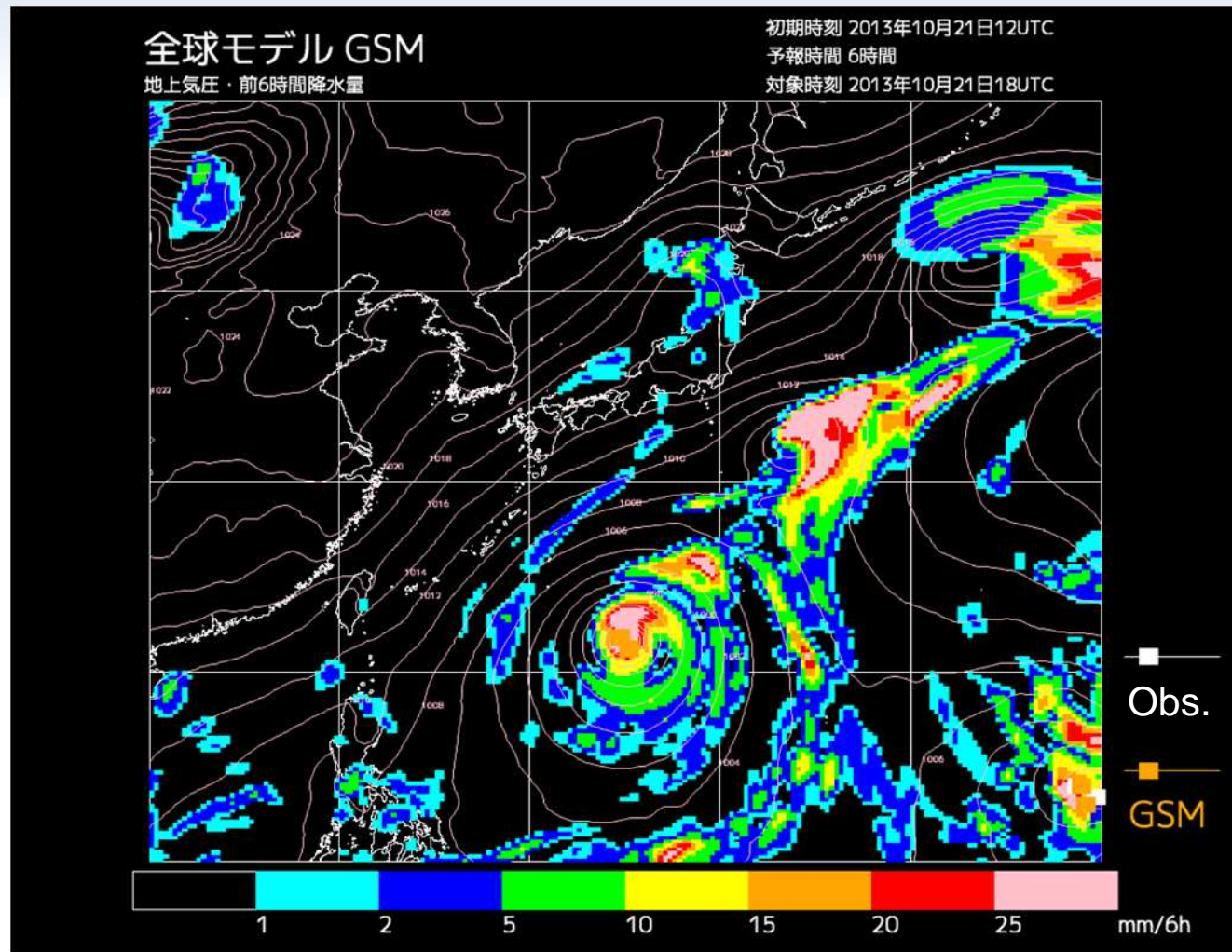
Smaller error

As a result of continuous development, typhoon position error has been continuously decreasing.

The accuracy of 120 hr forecast in 2013 compares with that of 72 hr forecast in early 1990's.

Example of Typhoon Forecast by 20km-GSM

- ✓ Accuracy of current NWP is generally good.
- ✓ GSM predicted typhoons track well.



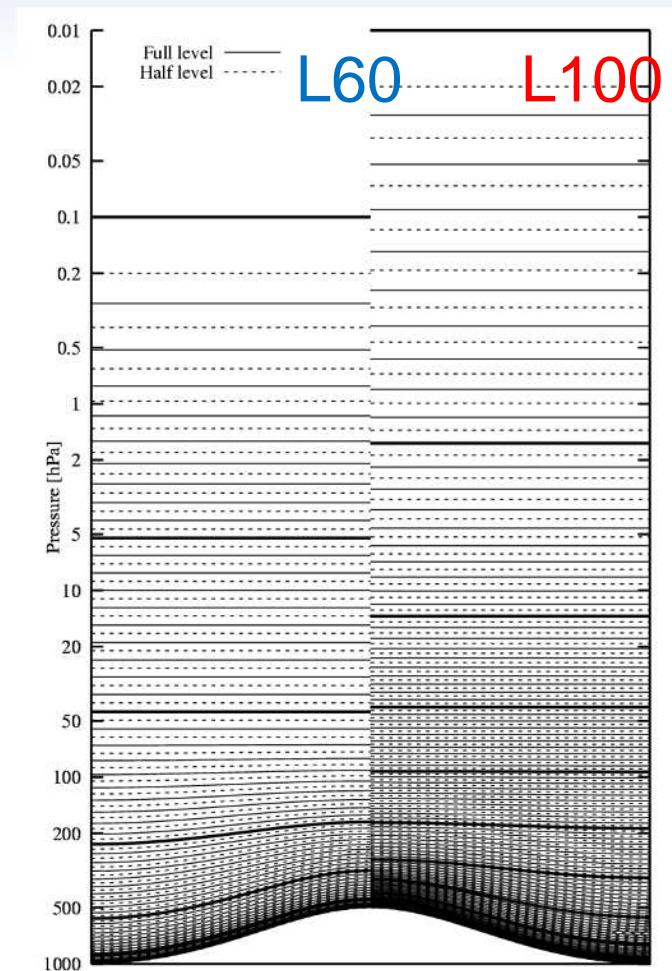
Development

– physics and dynamics-

- Recent changes
 - 28 Mar 2013: 11 days forecast (<- 9 days) for both deterministic and ensemble systems.
 - 25 Apr. 2013: Revise radiation scheme
 - Update aerosol optical depth climatology
 - Revise shortwave absorption by water vapor in radiation scheme (Collins et al. 2006)
 - *18? Mar. 2014:*
 - *Increasing the number of vertical layers from 60 to 100 (top: 0.1->0.01 hPa)*
 - *Revise physical processes*

Enhancement of GSM (Mar 2014)

- JMA plans to upgrade its operational GSM.
 - The number of vertical layers in GSM will be enhanced from 60 to 100.
 - the top level of the model will be raised from 0.1 hPa to 0.01 hPa.
- The physical processes will be revised.



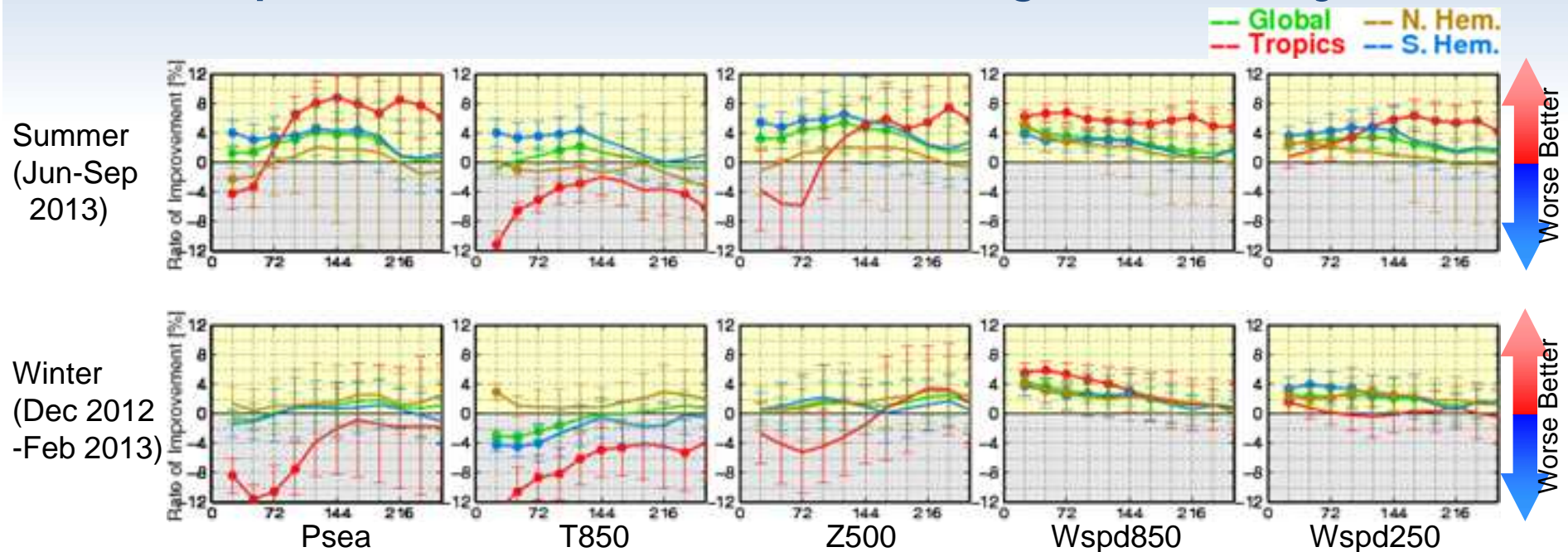
Update of physical processes

1. Revising a stable boundary layer scheme
→ Improving wind fields and diurnal temperature variation in stable conditions
2. Revising albedo parameters in the desert areas
→ Reducing clear sky radiation biases
3. Introducing two-stream approximation for long wave radiation scheme
→ Accelerating radiation code and improving the middle atmosphere temperature structure
4. Introducing a non-orographic gravity wave forcing scheme
→ Improving the middle atmosphere climate and representation of long-term oscillation in the tropical lower stratosphere such as QBO
5. Changing the application criteria of energy correction terms in convective parameterization
→ Improving general circulation and global precipitation distribution
6. Applying 2nd-order linear horizontal diffusion in the divergence equation and adjusting 4th-order linear diffusion as a sponge layer around the model top region
→ Improving the middle atmosphere forecast accuracy



Tropospheric scores

(improvement rate of RMSE against analysis)



Improvement rate of root mean square errors (RMSEs) against analysis between upgraded GSM and current GSM for Jun-Sep 2013 (top) and Dec 2012-Feb 2013 (bottom). Lines over yellow (gray) background area mean upgraded GSM shows better (worse) scores than current GSM.

The results of experiments show that the upgrade will have a positive impact on forecast scores mainly in the extra-tropics.

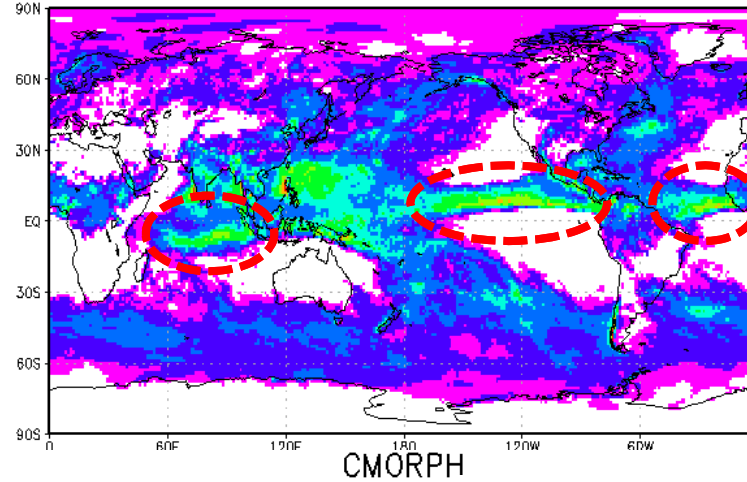
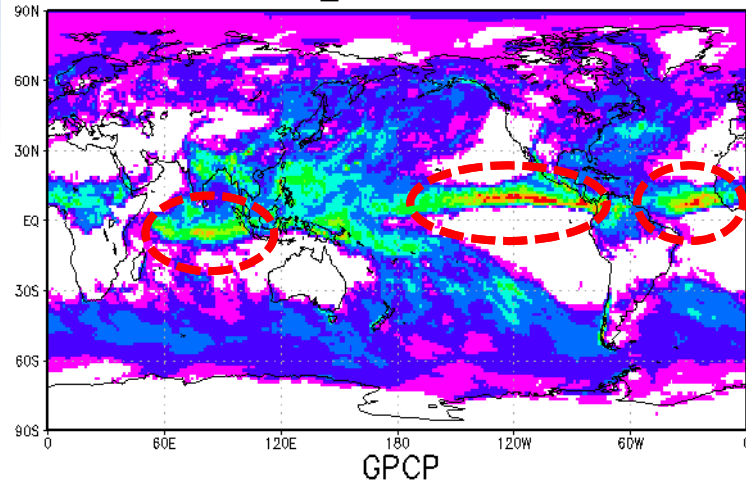
Negative impacts are seen for Psea and Z500 in the early forecast hours and for T850 in the tropics.

Precipitation

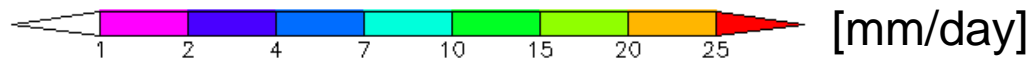
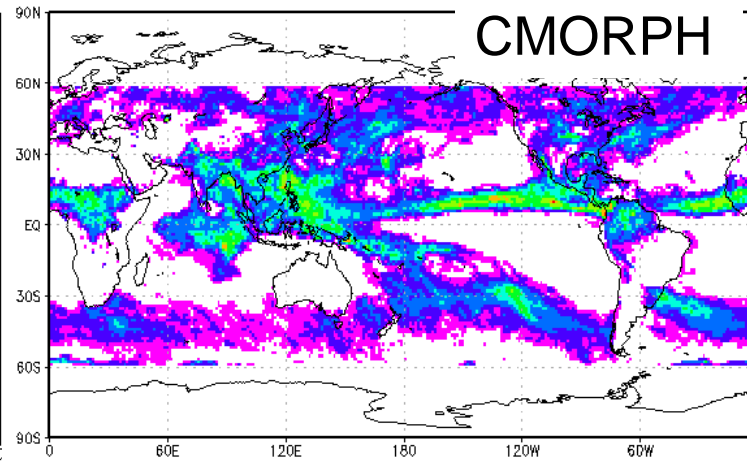
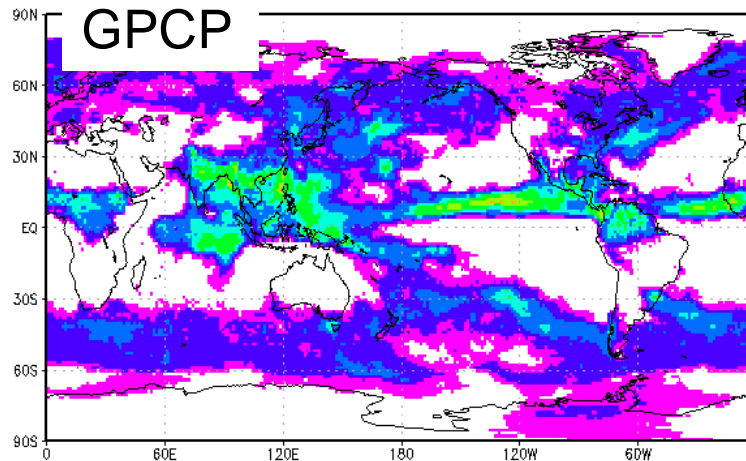
Current

Upgraded

H007-Cntl-2013sum_20130801-20130831 FT=2.100-Ef-v7-2013sum_20130801-20130831 FT=216



Aug 2013, FT=216
24-hour precipitation



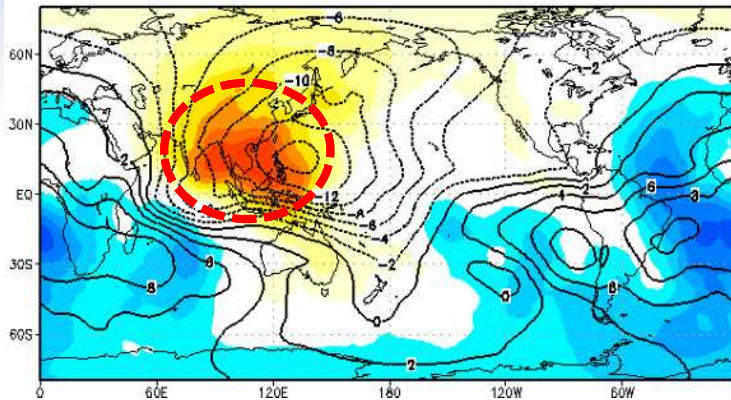
Excessive precipitation over the ITCZ, Indian Ocean and Atlantic Ocean is reduced.

General circulation

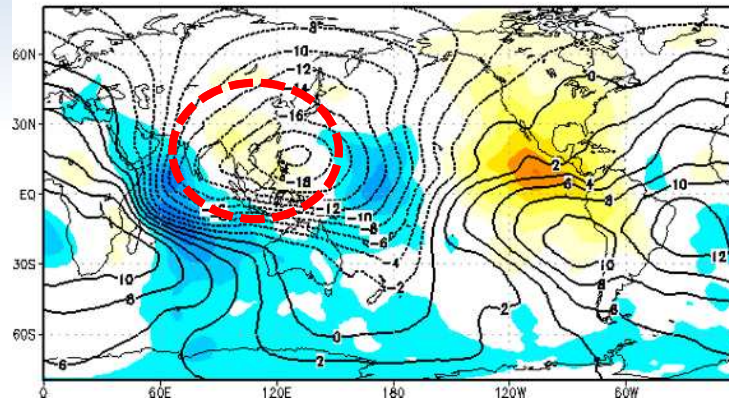
Current

Upgraded

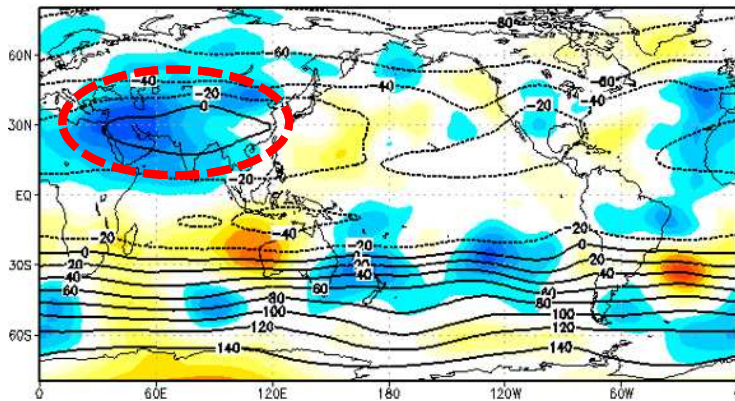
H007-Cntl-2013sum 200hPa Velocity potential day=9



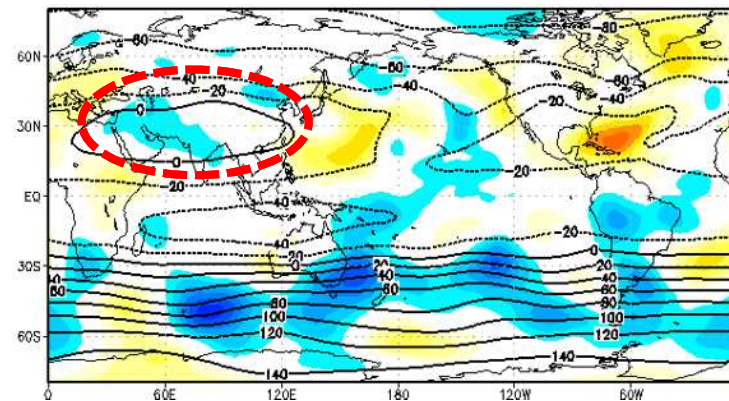
L100-Ef-v7-2013sum 200hPa Velocity potential day=9



H007-Cntl-2013sum 200hPa Stream function day=9



L100-Ef-v7-2013sum 200hPa Stream function day=9



Velocity potential at 200hPa

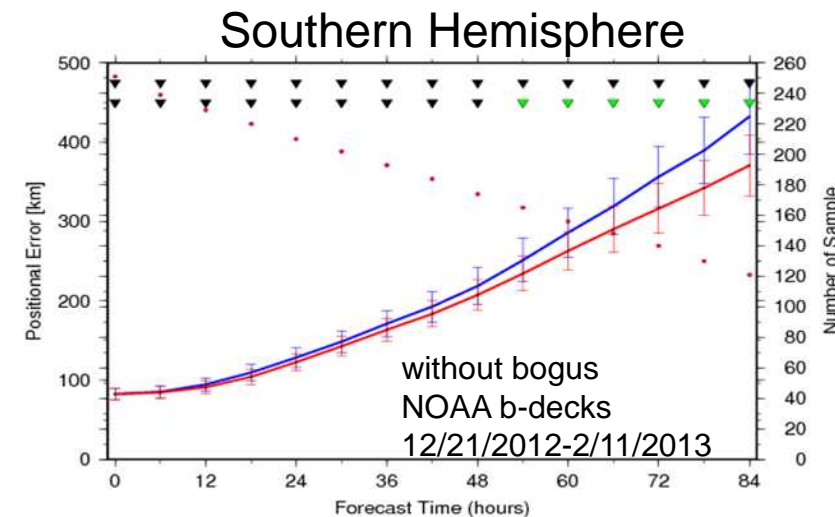
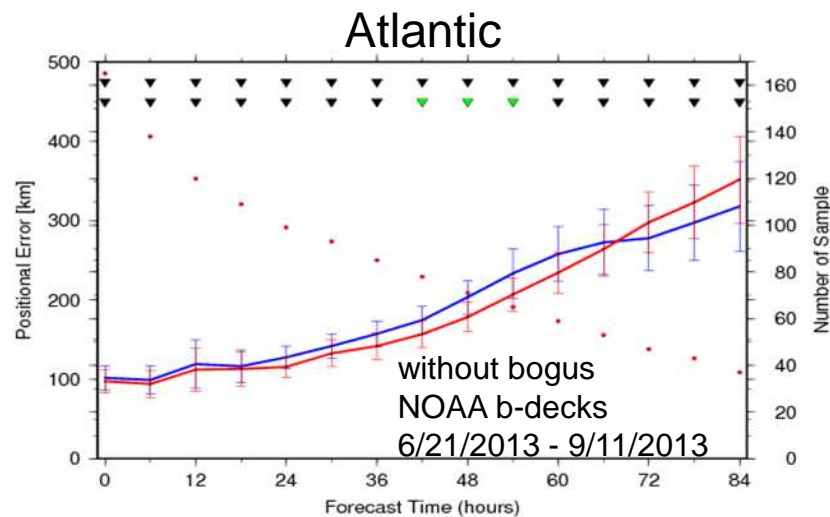
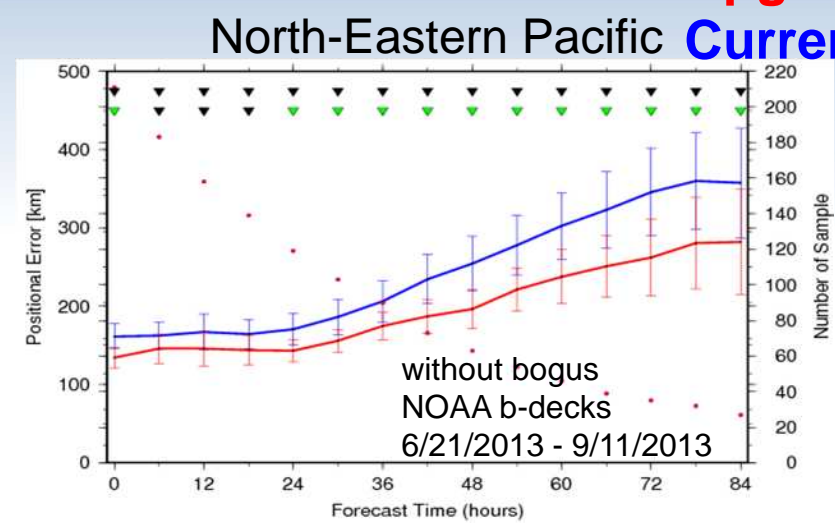
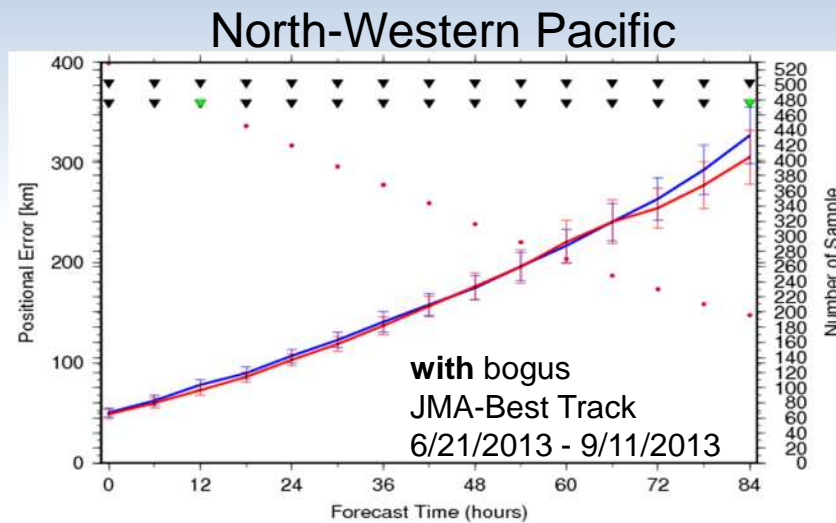
Stream function at 200hPa

Jul-Aug 2013, FT=216
Contour: forecast field
Shade: mean error

Representation of general circulation in the late forecast hours is improved.

Tropical cyclone track forecast errors

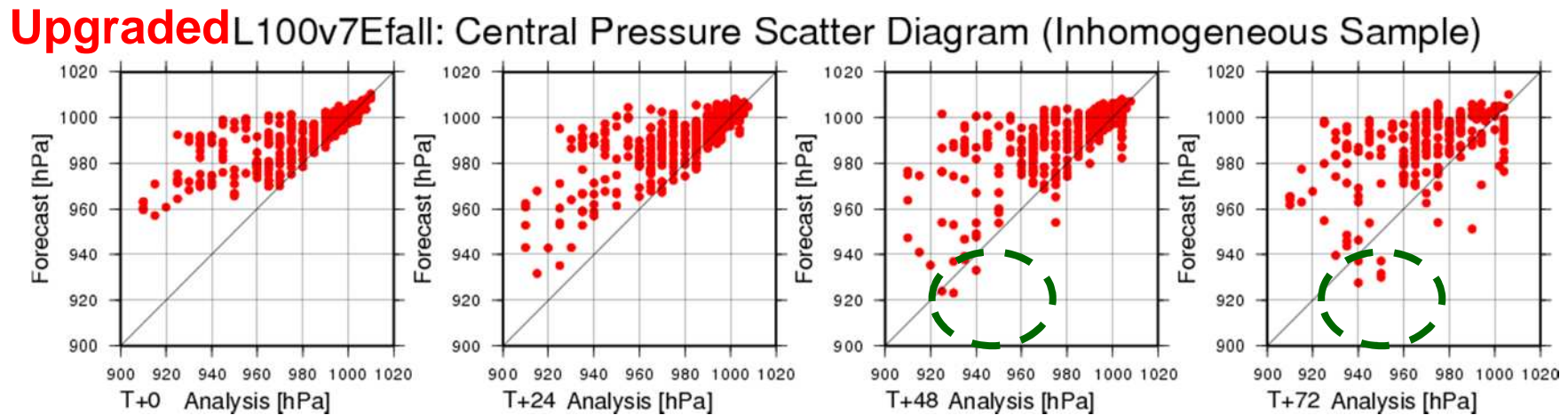
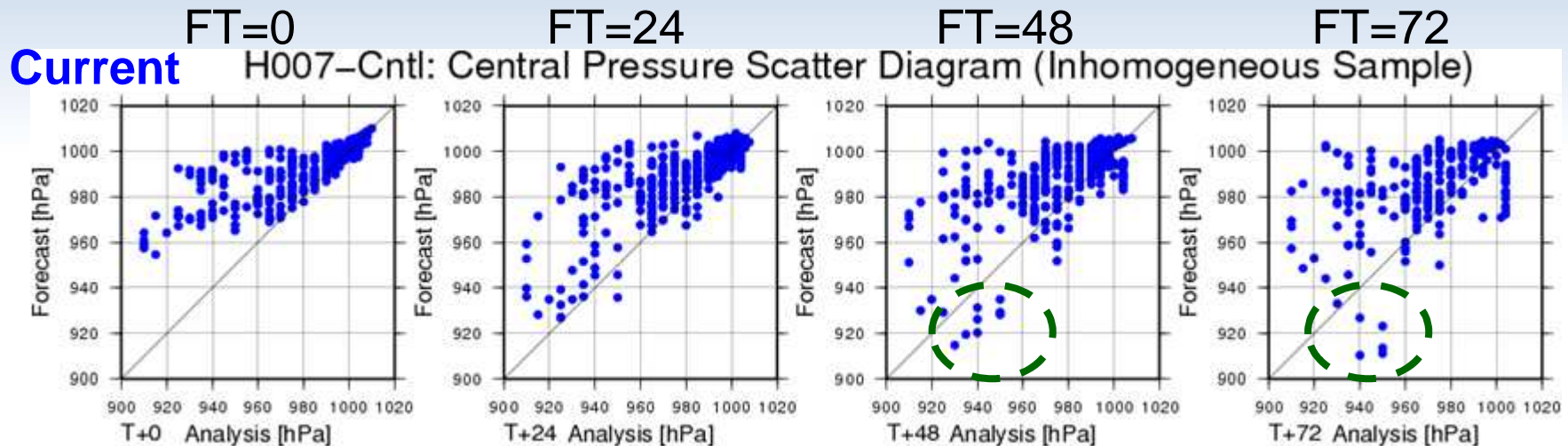
Upgraded
Current



The upgrade reduces TC track forecast errors in all four regions.

Another verification shows that the performance of new model for detection of cyclone existence is better than that of old model.

Tropical cyclone intensity errors



The upgrade reduces excessive development of TC.

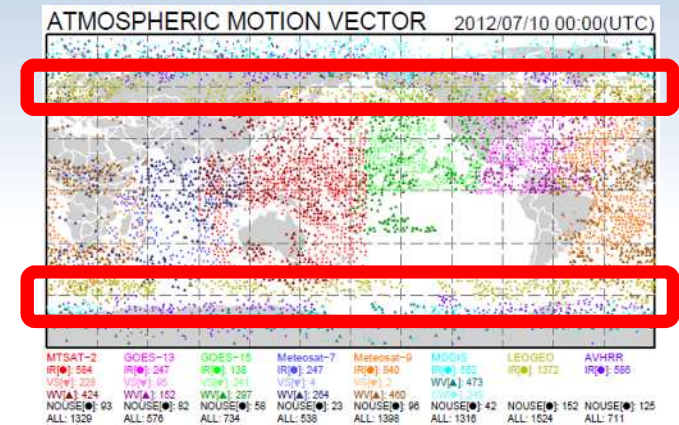
Development – assimilation, data-

- Recent changes

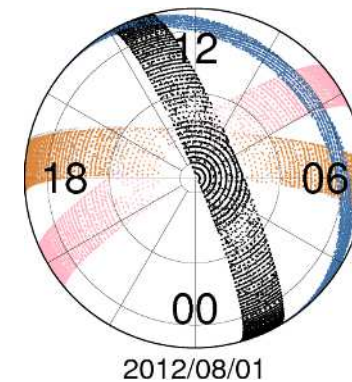
- 15 Nov. 2012: RTM upgrades (RTTOVv9.3→v10)
- 18 Dec. 2012: GNSS-RO observation operator upgrades
- *02 Jul. 2013: AVHRR, LEOGEO AMV*
- *12 Sep. 2013: Assimilation of JAXA's GCOM-W1/AMSR2 radiance data started*
- 16 Oct. 2013: Assimilation of SYNOP BUFR started
- *28 Nov 2013: Assimilation of GRAS, AMSU-A, MHS, ASCAT and AVHRR-AMV data from Metop-B started.*
- 18? Mar. 2014:
 - Assimilating AMSU-A channel 14
 - Assimilating GNSS-RO bending angle data at the altitude up to 60km (currently, refractivity data up to 30 km)
 - Assimilating ground-based GNSS-ZTD (Zenith Total Delay) data

Recent improvements of Global data assimilation system

- Enhancement of utilized atmospheric motion vectors (AMVs) (July 2013)
 - AMV data coverage. **The red rectangles** indicate areas covered by LEOGEO AMVs.

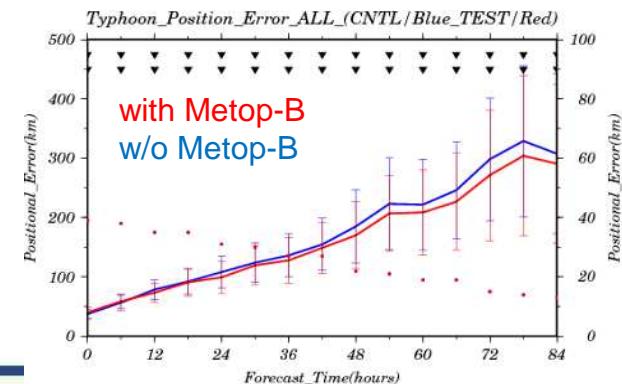


- Introduction of AMSR2 onboard GCOM-W1 (Japanese name: Shizuku) (September 2013)
 - MW imager data coverage. GCOM-W1/AMSR2 data fill the gaps. Note: DMSP-F16 and F17 had almost the same coverage as of summer 2012.



DMSP-F16/SSMIS
 DMSP-F17/SSMIS
 DMSP-F18/SSMIS
 GCOM-W1/AMSR2
 TRMM/TMI

- Introduction of data from Metop-B
 - Mean TC position errors (in km) as a function of forecast time up to 84 hours in summer 2013. The red and blue lines indicate errors of forecasts with and without Metop-B data, respectively. The dots correspond to the vertical axis on the right, which represents the number of verification samples.



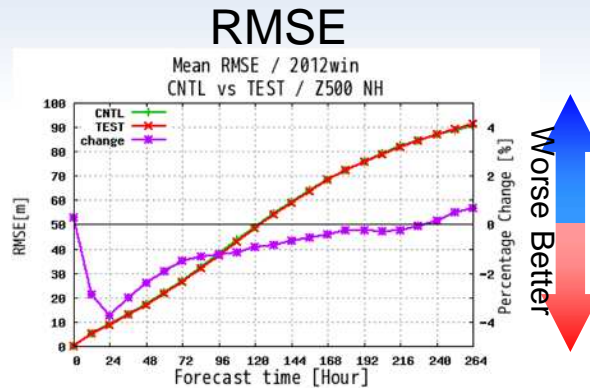
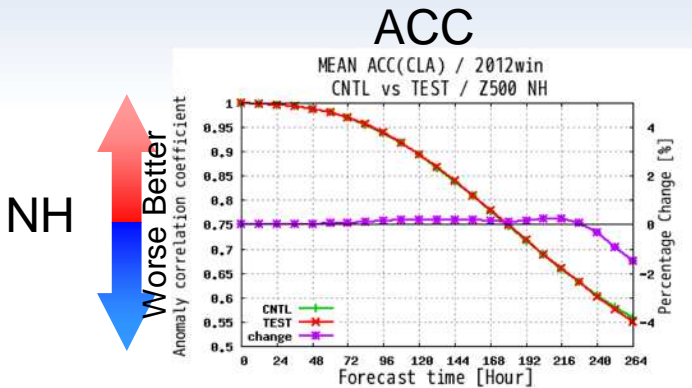
Development – EPSs -

- Recent changes
 - 28 Mar 2013: 11 days forecast (← 9 days) for both deterministic and ensemble system.
 - *26 Feb. 2014 : Upgrade of One-week EPS*
 - *Increase model resolution (from TL319L60 to TL479L60)*
 - *Increased frequency of operation (from once a day to twice a day)*
 - *11 Mar. 2014: Upgrade of Typhoon EPS*
 - *Increase model resolution (from TL319L60 to TL479L60)*
 - *Increase ensemble members (from 11 to 25)*
- Under development
 - 2014: Start test operation of Meso-scale regional EPS

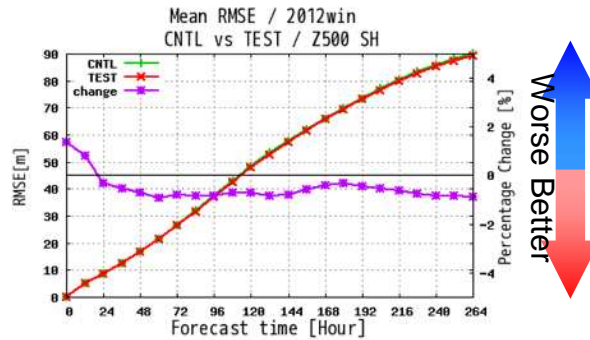
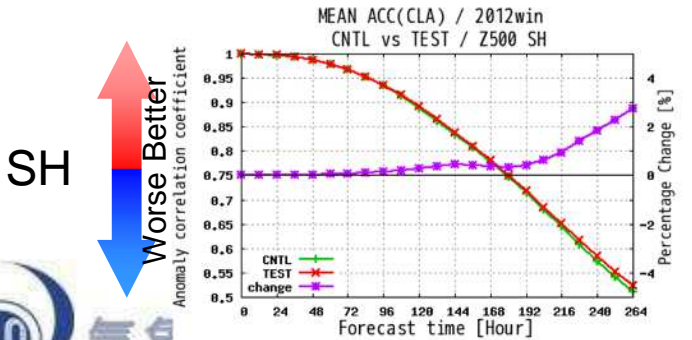
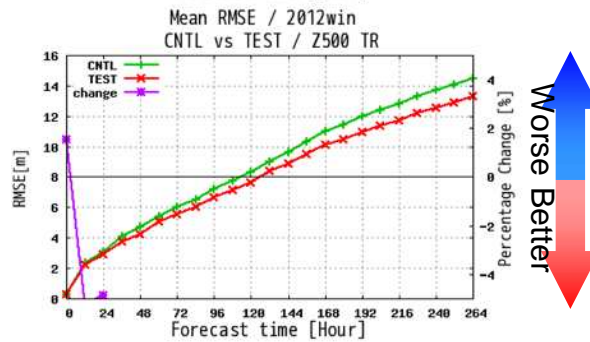
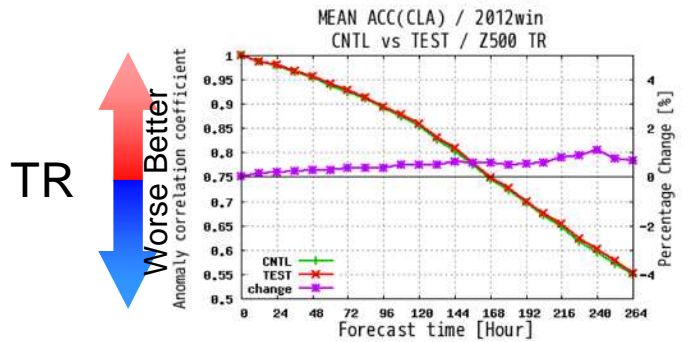
Upgrade of global EPSs (Feb and Mar 2014)

		One-week EPS	Typhoon EPS
Objectives		One-week Forecasts	TC Information
EPS model and its integration	Model type	GSM (an atmospheric general circulation model)	
	Horizontal resolution	TL319 (~55km) → TL479 (~40km)	
	Vertical levels	60 levels, up to 0.1 hPa	
	Forecast range	264 hours (12UTC) → 264 hours (00, 12UTC)	132 hours(00,06,12,18UTC) only when Tropical Cyclones of TS/STS/TY intensity are present or are expected to appear in the RSMC Tokyo –Typhoon Centre’s area of responsibility
Ensemble settings	Member (per day)	51 → 27 (51/day → 54/day)	11 → 25 (44/day → 100/day)
	Initial perturbation	SV method, Three target areas (NH,TR,SH)	SV method, One fixed target area (the Northwestern Pacific) and up to 3 movable target areas (vicinities of up to 3 TCs)
	Model ensemble	Stochastic physics	

Ensemble mean Z500



Red : Upgraded
Green : Old
Purple :
Improvement ratio



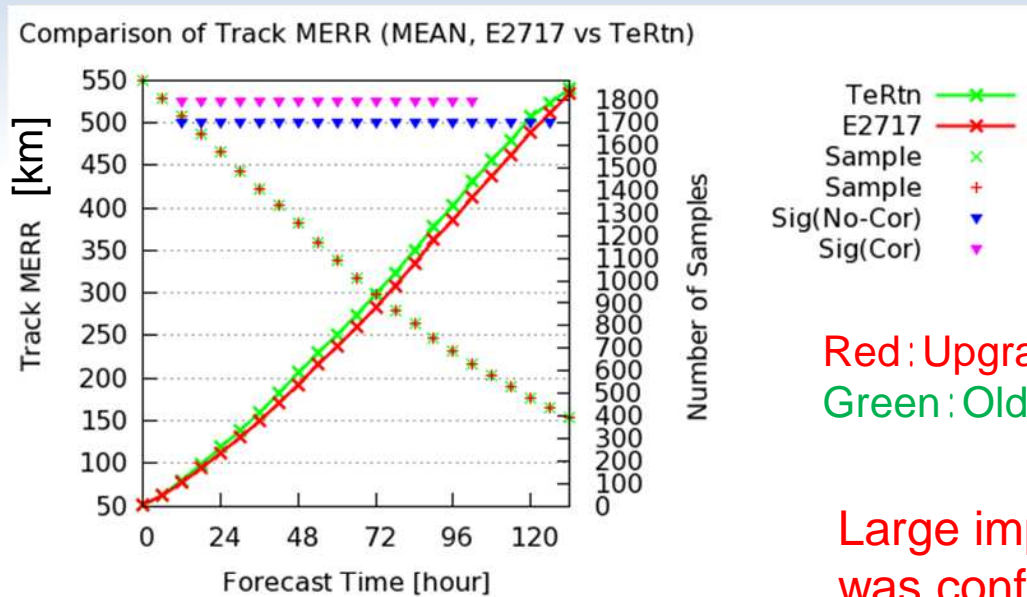
Mean anomaly correlation coefficients (left) and RMSE (right) for Z500 of ensemble mean forecasts for December 2011 to February 2012.

Upgrade of global EPSs (Feb and Mar 2014)

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	Model ensemble	Stochastic physics	

TC track forecast error (Ensemble mean)

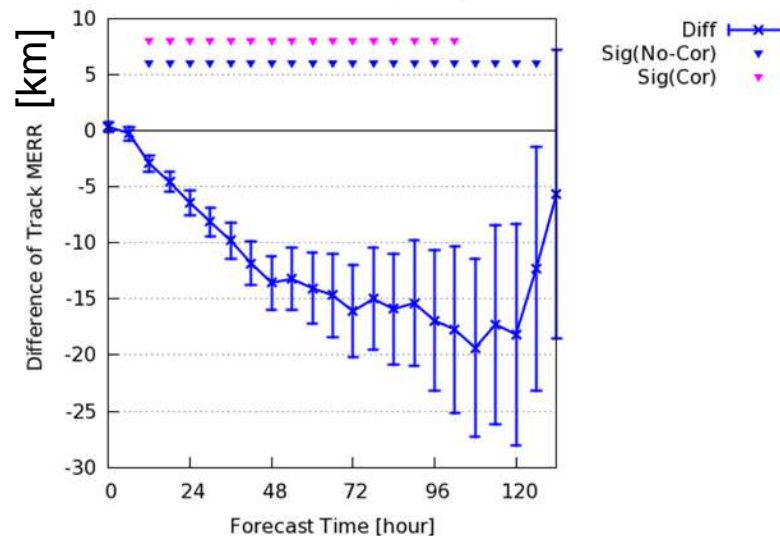
Mean Error



Red : Upgraded
Green : Old

Large improvement was confirmed !

Mean Error Difference

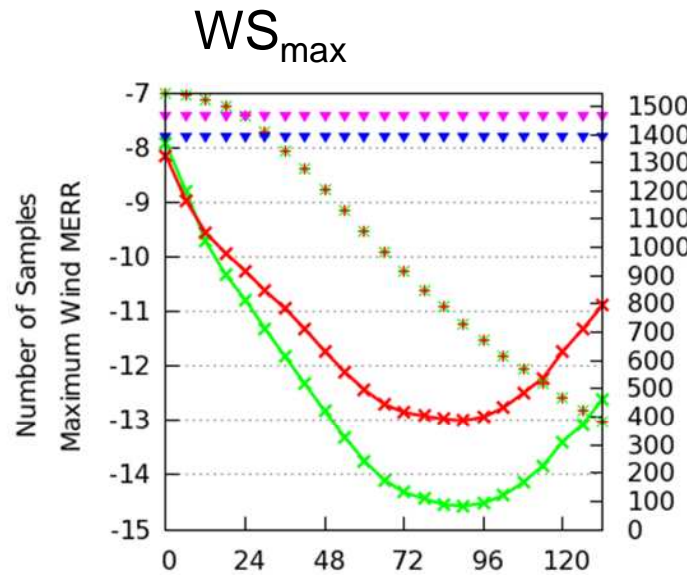
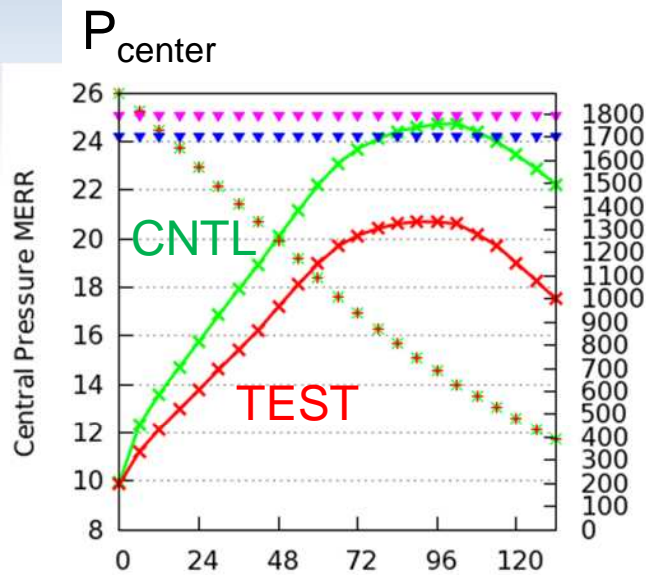


Mean TC position errors (in km) of ensemble mean forecasts for April 2011 to November 2013.

“+” correspond to the vertical axis on the right, which represents the number of verification samples.

Typhoon Intensity (Ensemble mean)

Mean Error

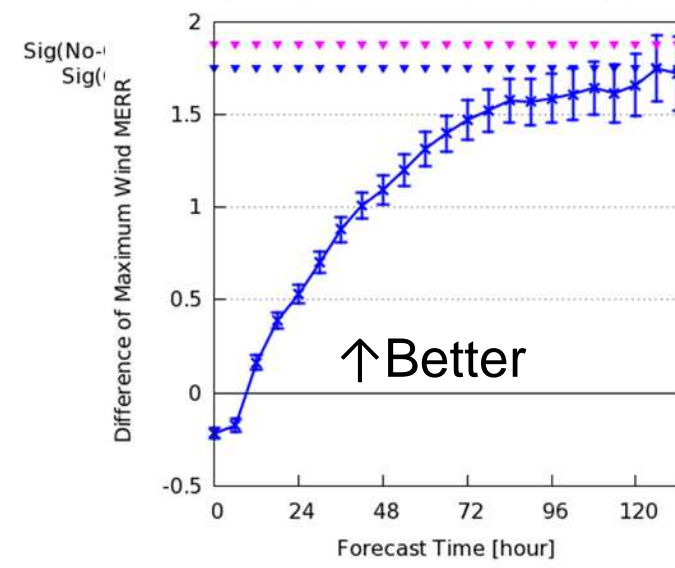
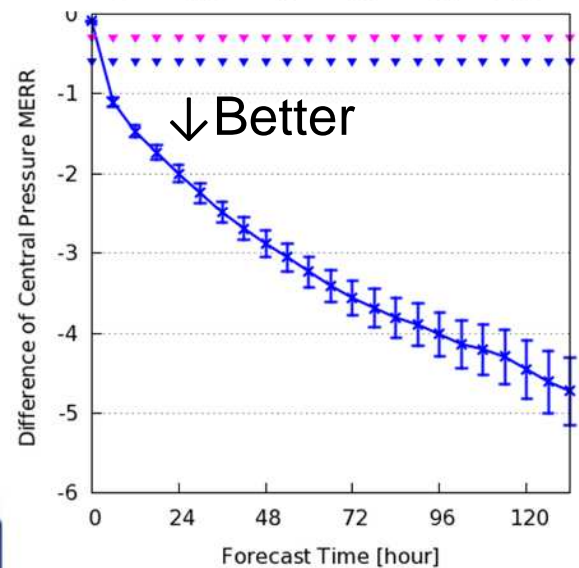


TeRtn —x—
 E2717 —x—
 Sample x
 Sample +
 Sig(No-Cor) ▼
 Sig(Cor) ▼

Red : Upgraded
 Green : Old

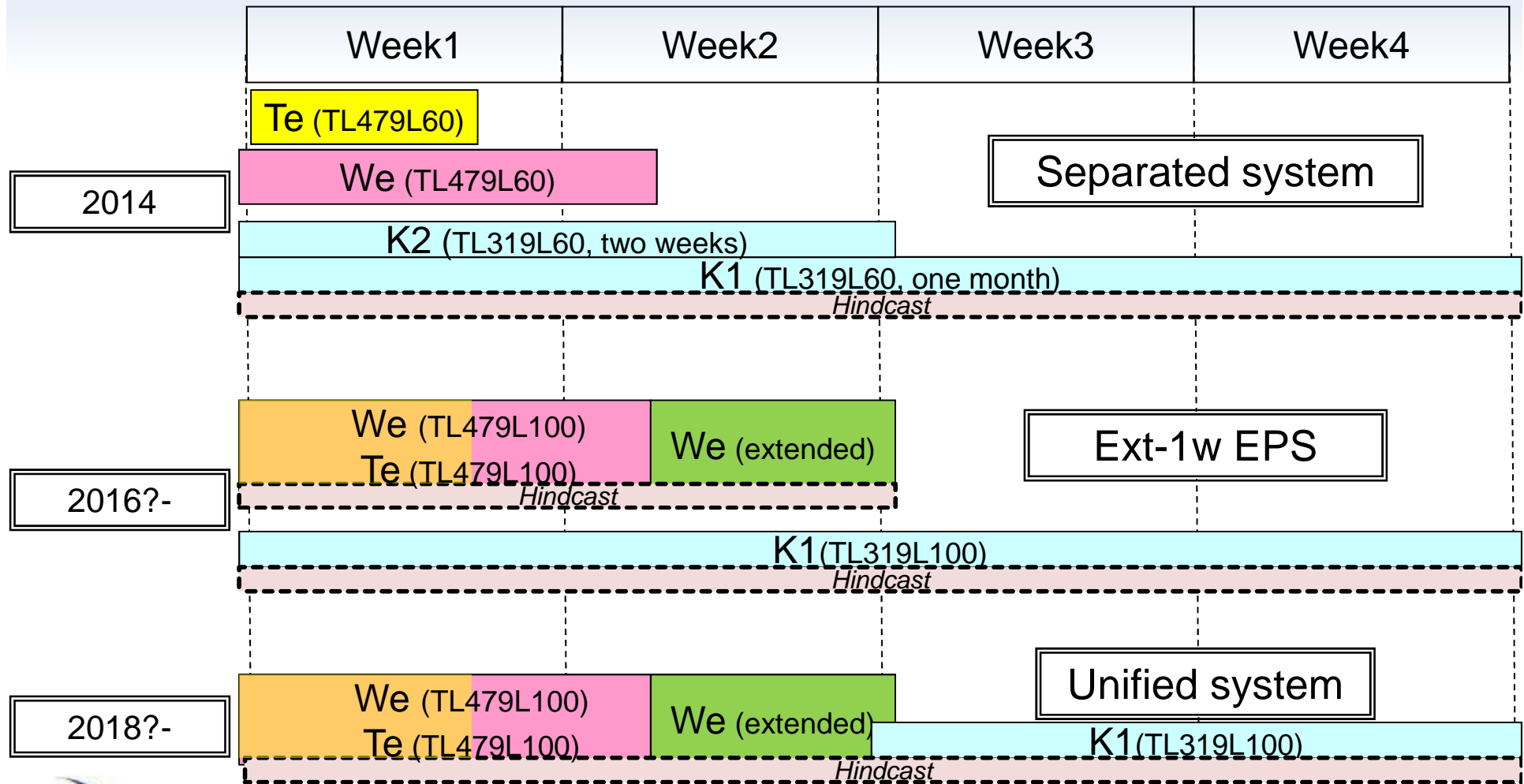
Large improvement was confirmed !

Mean Error Difference



Mean TC intensity errors of ensemble mean forecasts for April 2011 to November 2013. “+” correspond to the vertical axis on the right, which represents the number of verification samples.

Future plan of medium range and one month ensemble prediction system



WGNE INTERCOMPARISON OF TROPICAL CYCLONE TRACK FORECAST

WGNE

(Working Group on Numerical Experimentation)

- Numerical Weather Prediction (CAS) and Climate (WCRP)
 - Working interface between operational forecasting and climate modelling communities
- WGNE fosters the open exchange of information in a competitive NWP environment
- WGNE theme: atmospheric models, their evaluation and improvement

WGNE Activities

- Meeting
- Related Workshop
- Intercomparison, Verification
 - Tropical Cyclone
 - Precipitation
 - Surface drag
 - Impact of aerosol



28TH SESSION OF THE WORKING GROUP ON NUMERICAL EXPERIMENTATION (WGNE-28)

Toulouse, France, 5-9 November 2012

Prepared by

Andy Brown¹, Christian Jakob¹ and Jean-Noël Thépaut²
¹Co-Chairs and ²In-coming Co-Chair of WGNE



WGNE is a Joint Working Group of the Commission for Atmospheric Sciences
and the
World Climate Research Programme



WGNE intercomparison of Tropical Cyclone Track forecast, 2012

Chiashi Muroi, colleagues at JMA, and WGNE-Friends

10-13 Mar. 2014, Melbourne

WGNE-29

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.

2013: 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.

Specification of Data

NWP centers	Participate Year	Bogus data / Relocation	Horizontal Res. of provided data	Model Res. as of 2012
BoM	2003	-	1.25x0.833(~Mar 27) 0.562x0.375(Mar 28~)	80kmL50 (~Mar 27) 40kmL70 (Mar 28~)
CMA	2004	used	1.25x1.25	T _L 639L60
CMC	1994	-	1.0x1.0	33km L60
DWD	2000	-	0.25x0.25	30kmL60 (~Feb 29) 20kmL60 (Mar 01~)
ECMWF	1991	-	0.125x0.125	T _L 1279L91
JMA	1991	used in WNP	0.25x0.25	T _L 959L60
KMA	2011	used	0.3515x0.2345	25kmL70
France	2004	used* ¹	0.5x0.5	T _L 798C2.4L70
NCEP	2003	used in NH	1.0x1.0	T574 L64 EnKF/Var
NRL	2006	used	1.0x1.0	T319L42
UKMO	1991	used* ²	0.3515x0.2345	25kmL70

*¹ except for South Pacific and north Indian-Ocean

*² terminate the use of bogus data on July 17, 2012

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 +12hr)** : search from the first position
- c) **Third and after (FT +24hr~)** : search from estimated position
from the latest two positions

(all position searched within 500km radius)

2. Verification Method

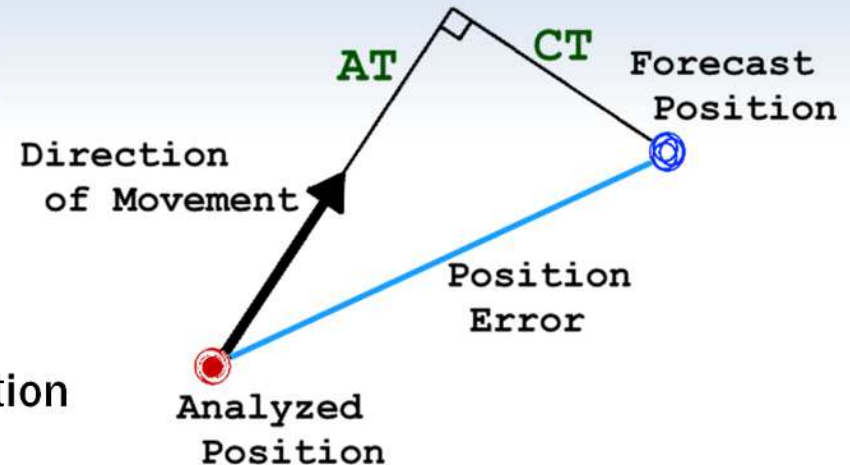
- **Position Error (km)**

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**

$$\text{Detection Rate (t)} = A(t) / B(t)$$

$A(t)$: 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 .

TC Verification

TC tracks on 2012 season

Northern-Hemisphere [2012/01/01 to 2012/12/31]

Southern-Hemisphere [2011/09/01 to 2012/08/31]

Number of TCs , [best-track data provider]

25 western North-Pacific [RSMC Tokyo]

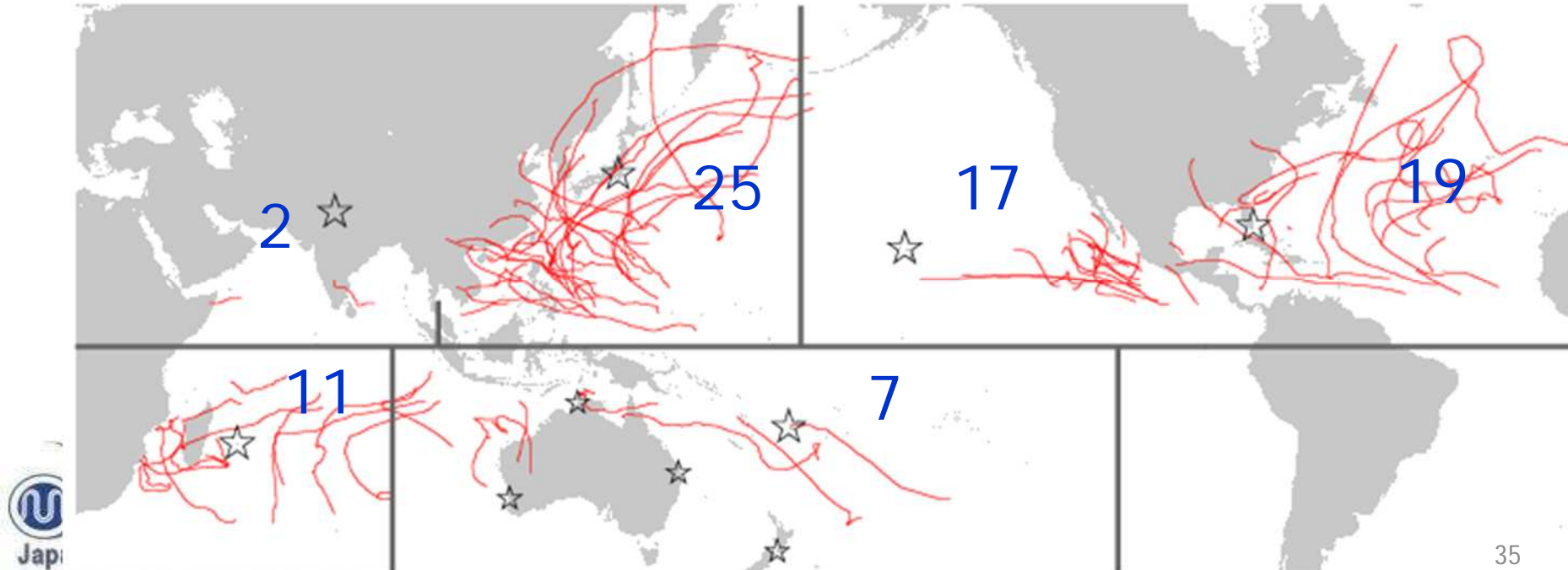
17 eastern North-Pacific (including Central-Pacific) [RSMC Miami, Honolulu]

19 North Atlantic [RSMC Miami]

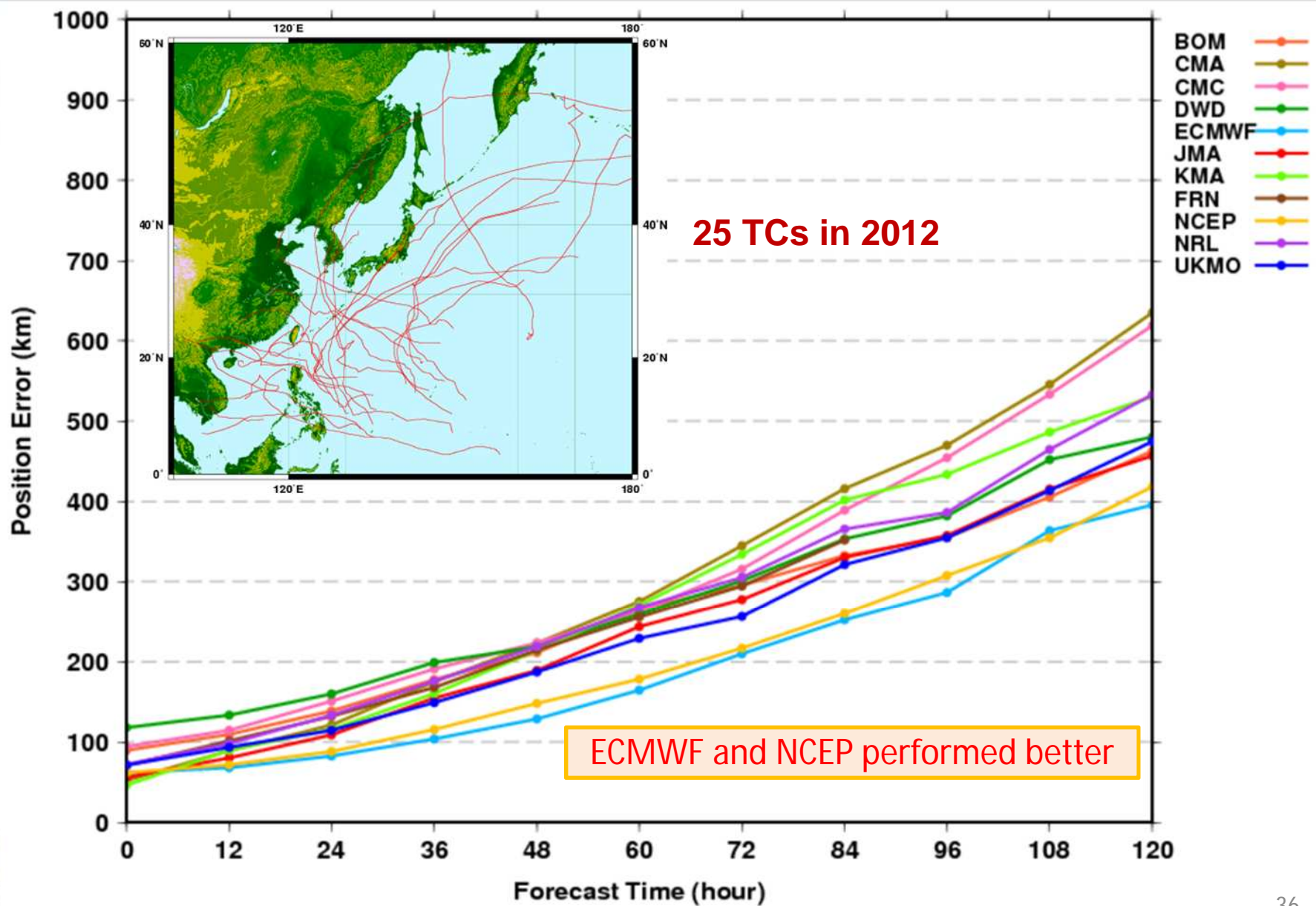
2 north Indian-Ocean [RSMC New-Delhi]

11 south Indian-Ocean [RSMC La-Reunion]

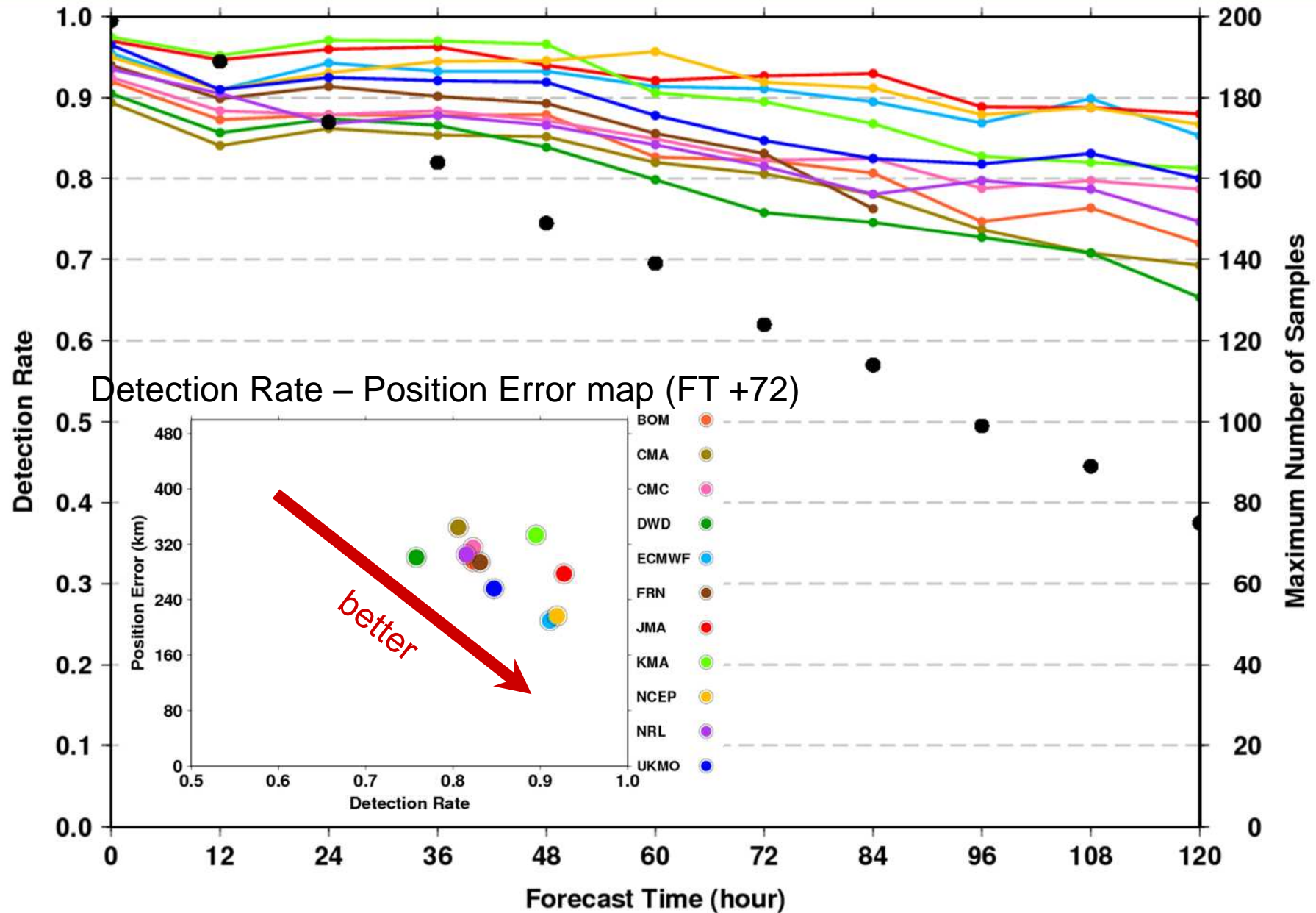
7 around Australia [RSMC Nadi and 4 TCWCs]



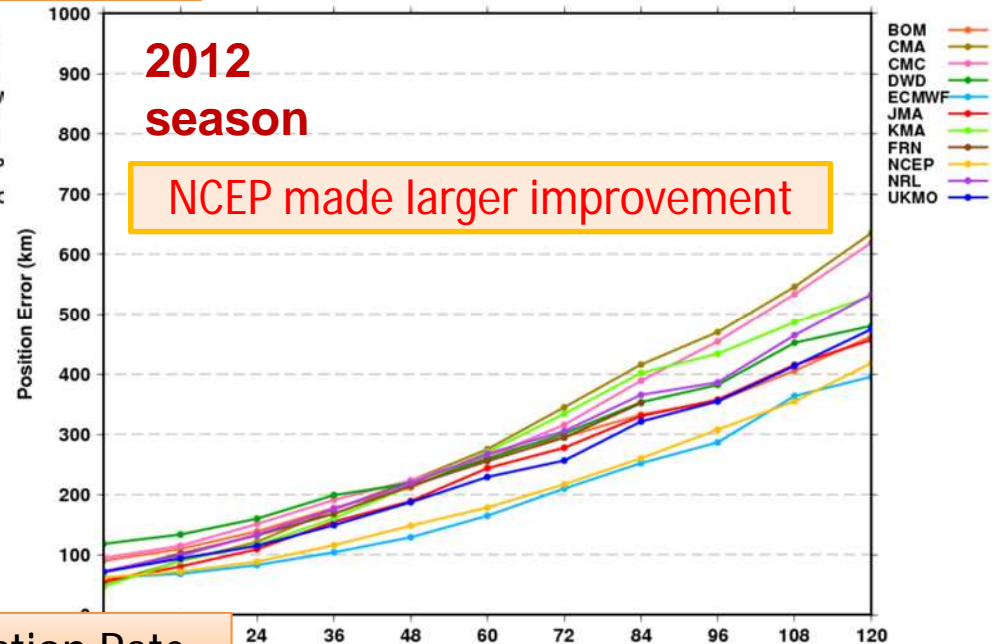
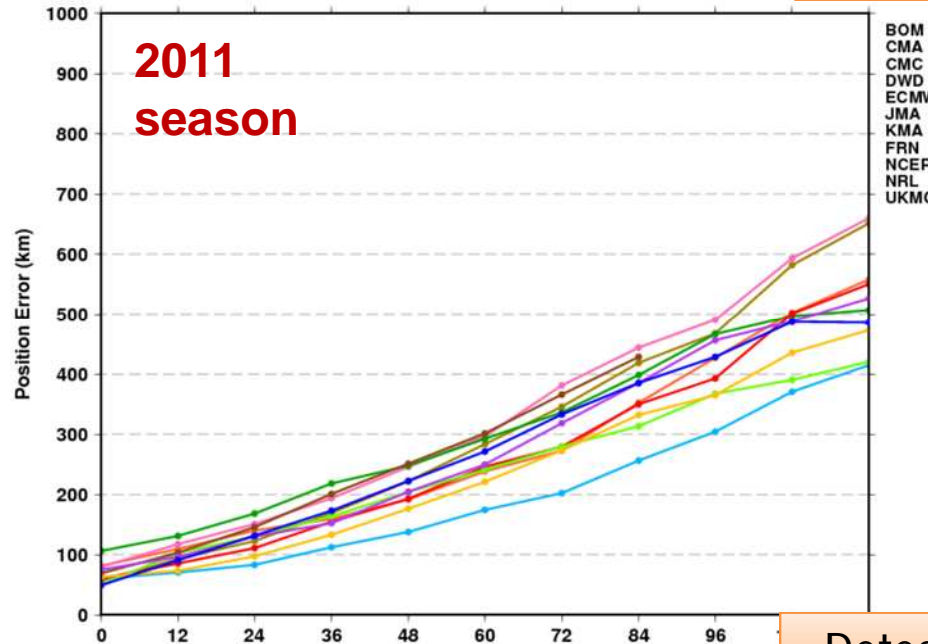
western North-Pacific (WNP) domain Position Error



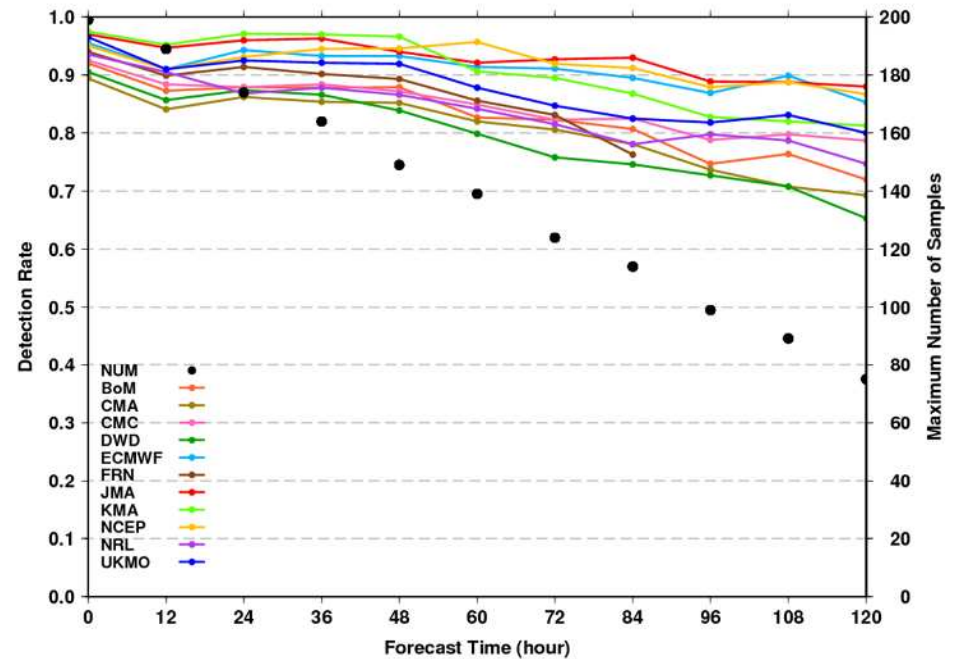
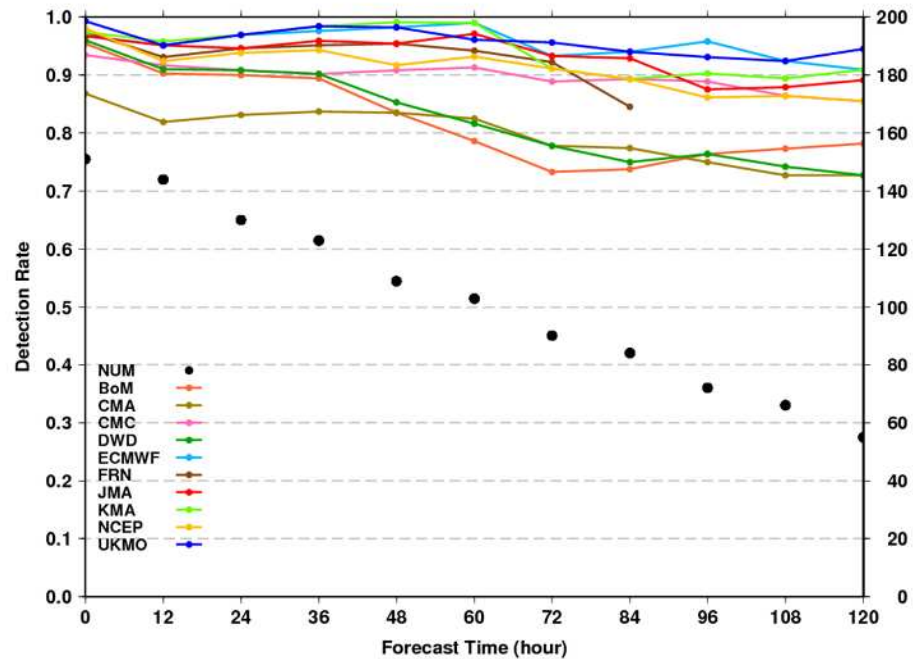
WNP domain Detection Rate



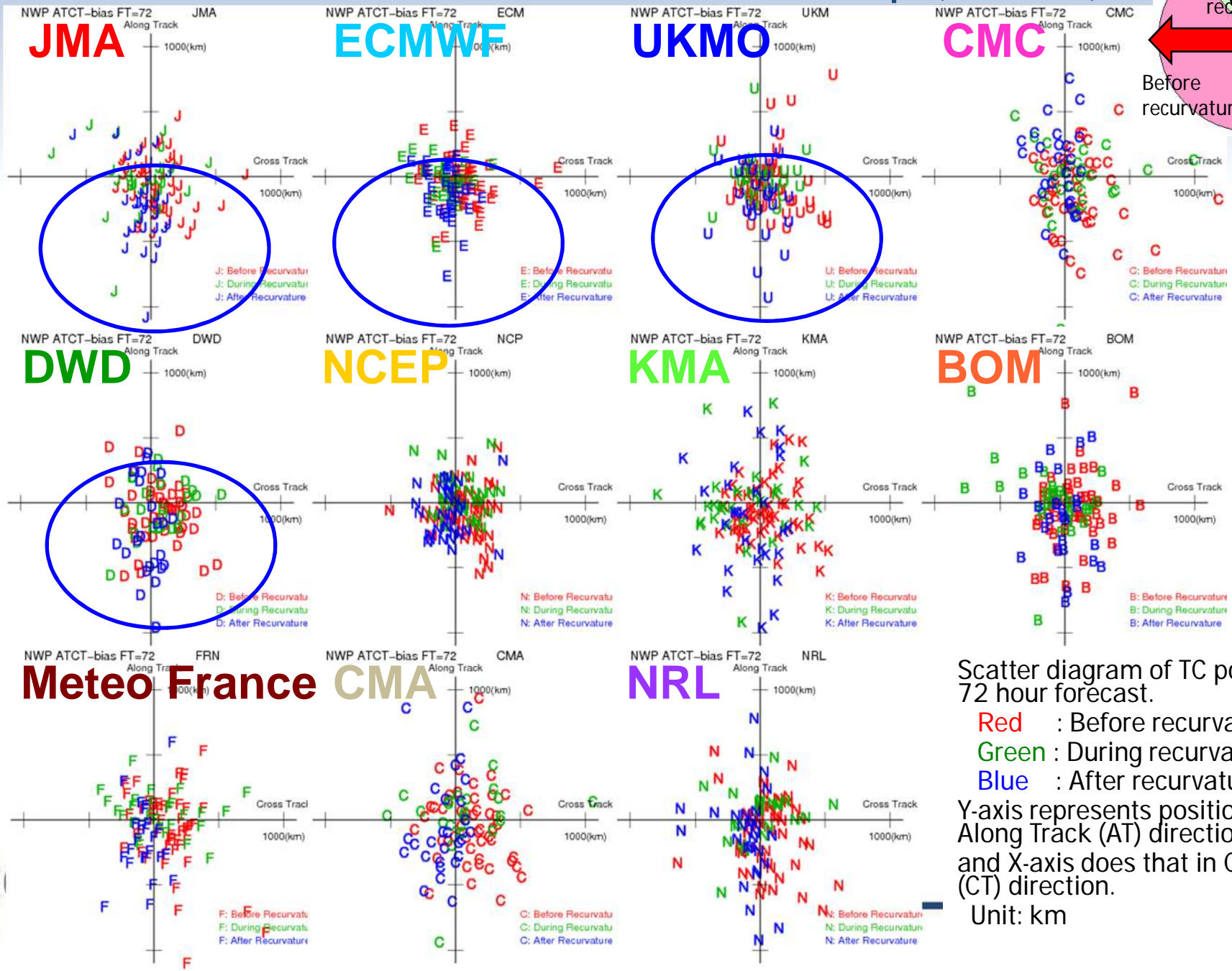
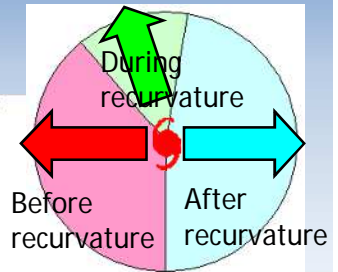
Position Error



Detection Rate



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



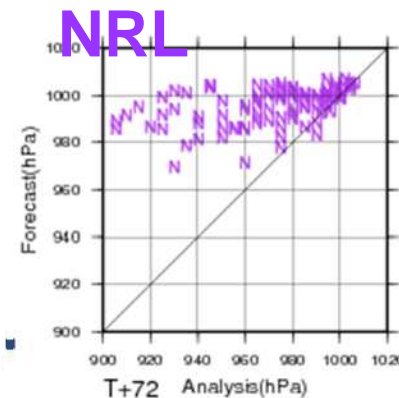
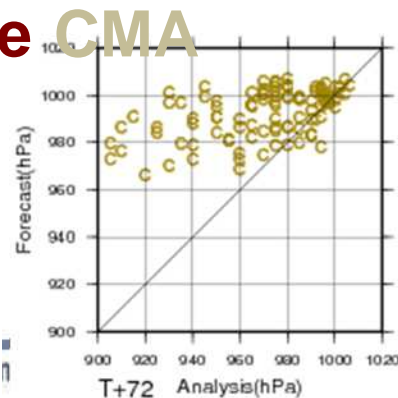
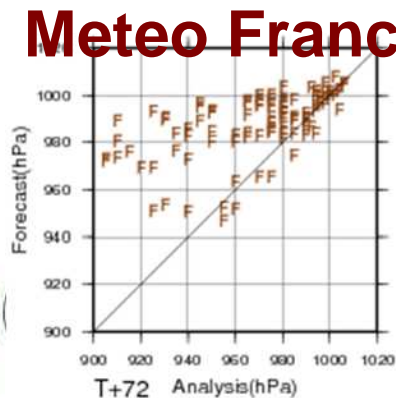
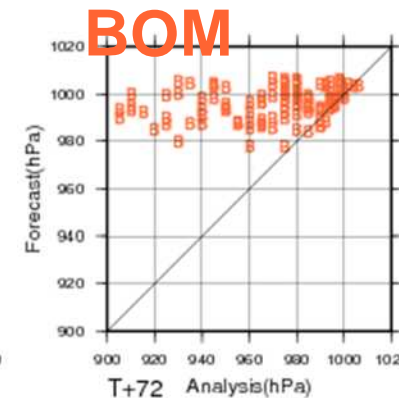
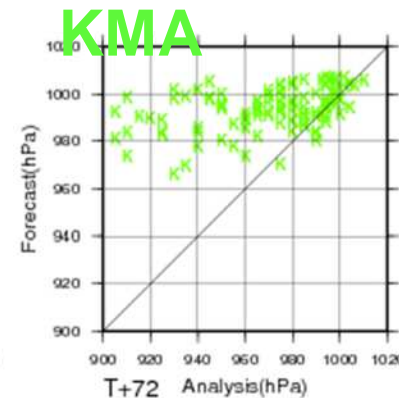
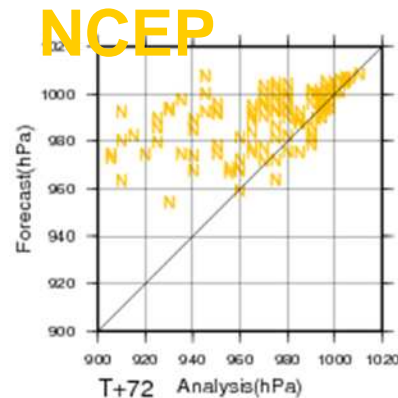
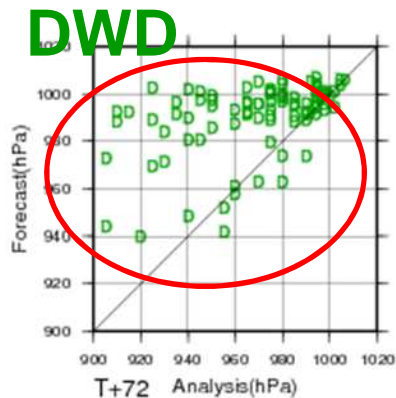
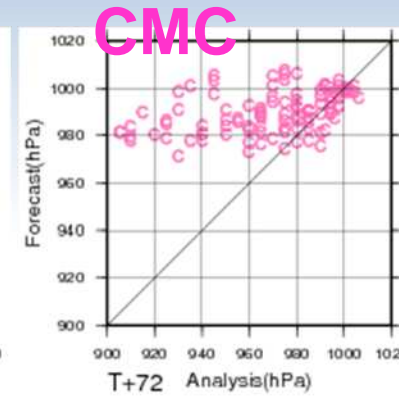
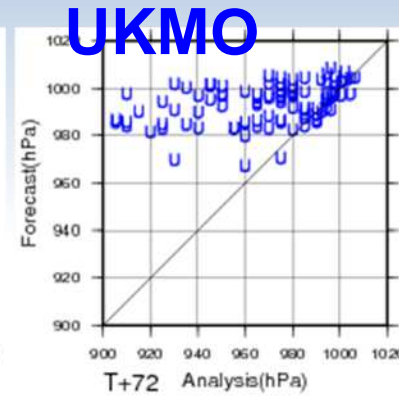
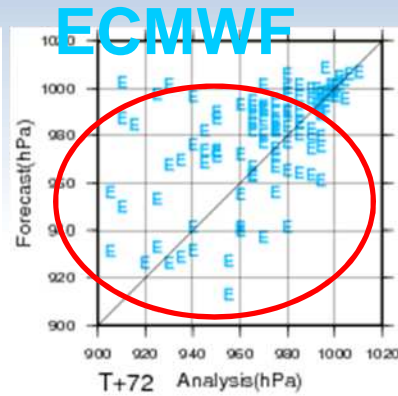
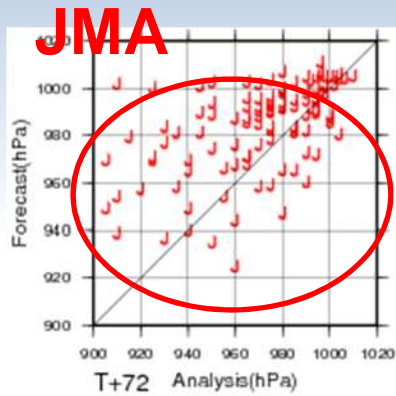
Scatter diagram of TC positions at 72 hour forecast.

- 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

WNP domain Central Pressure scatter diagram (FT +72)

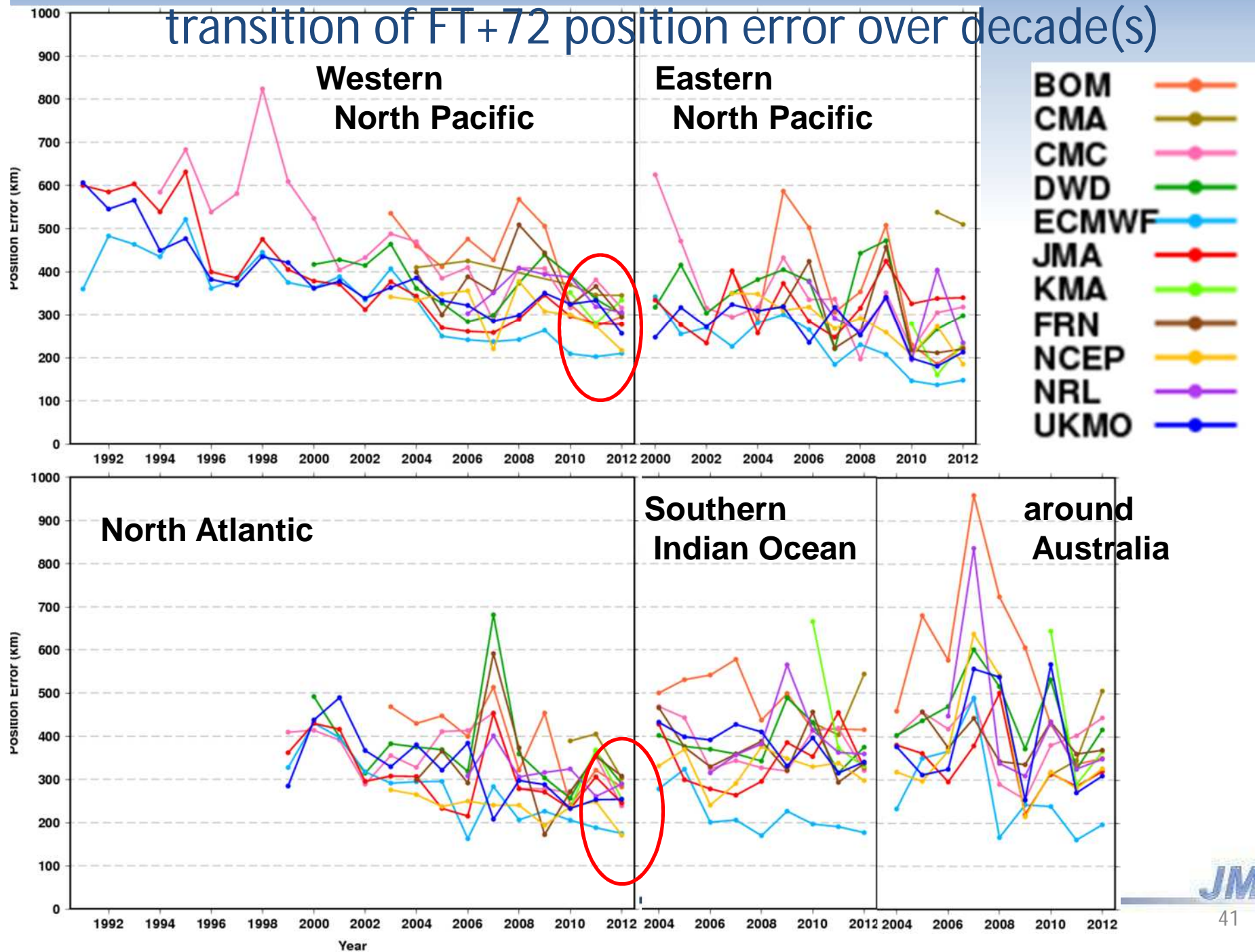


Scatter diagram of central pressure at 72 hour forecast.

Y-axis represents central pressure of forecast and X-axis does that of analysis.

Unit: hPa

transition of FT+72 position error over decade(s)





SUMMARY

Summary (1)

- JMA plans to upgrade its operational Global Spectral Model (GSM) in March 2014. The results of experiments show that the upgrade will have a positive impact on forecast including typhoon (track and intensity) forecast.
- JMA upgraded its One-Week EPS and Typhoon EPS. The upgrade includes enhancement of the horizontal resolution of the forecast model from TL319 to TL479 for both EPSs.
- The upgrade for the One-Week EPS includes increased frequency of operation from once a day to twice a day and an approximate halving of each ensemble size (from 51 to 27). The results of related experiments show that the upgrade will have a positive impact on forecast scores for both ensemble mean and probabilistic forecasts.
- The upgrade for the Typhoon EPS includes increased ensemble size from 11 to 25 for improved reliability of TC strike probability forecasts. The results of related experiments show that the upgrade will have a positive impact on TC track and intensity forecasts in both ensemble mean and control runs.

Summary (2)

- WGNE encourages numerical model development for both NWP and climate.
- JMA collects forecast data from participating NWP centers, verifies TC track forecasts and reports the verification results at the WGNE meeting every year.
- TC verification of WGNE shows remarkable improvements of operational Global NWP models in all centers.
 - Enhancement of resolution, physical process and data assimilation are key points.

BACKUP SLIDES