Systematic Error in Tropical Cyclone Track Forecasts from Operational Global Models

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Courtesy of
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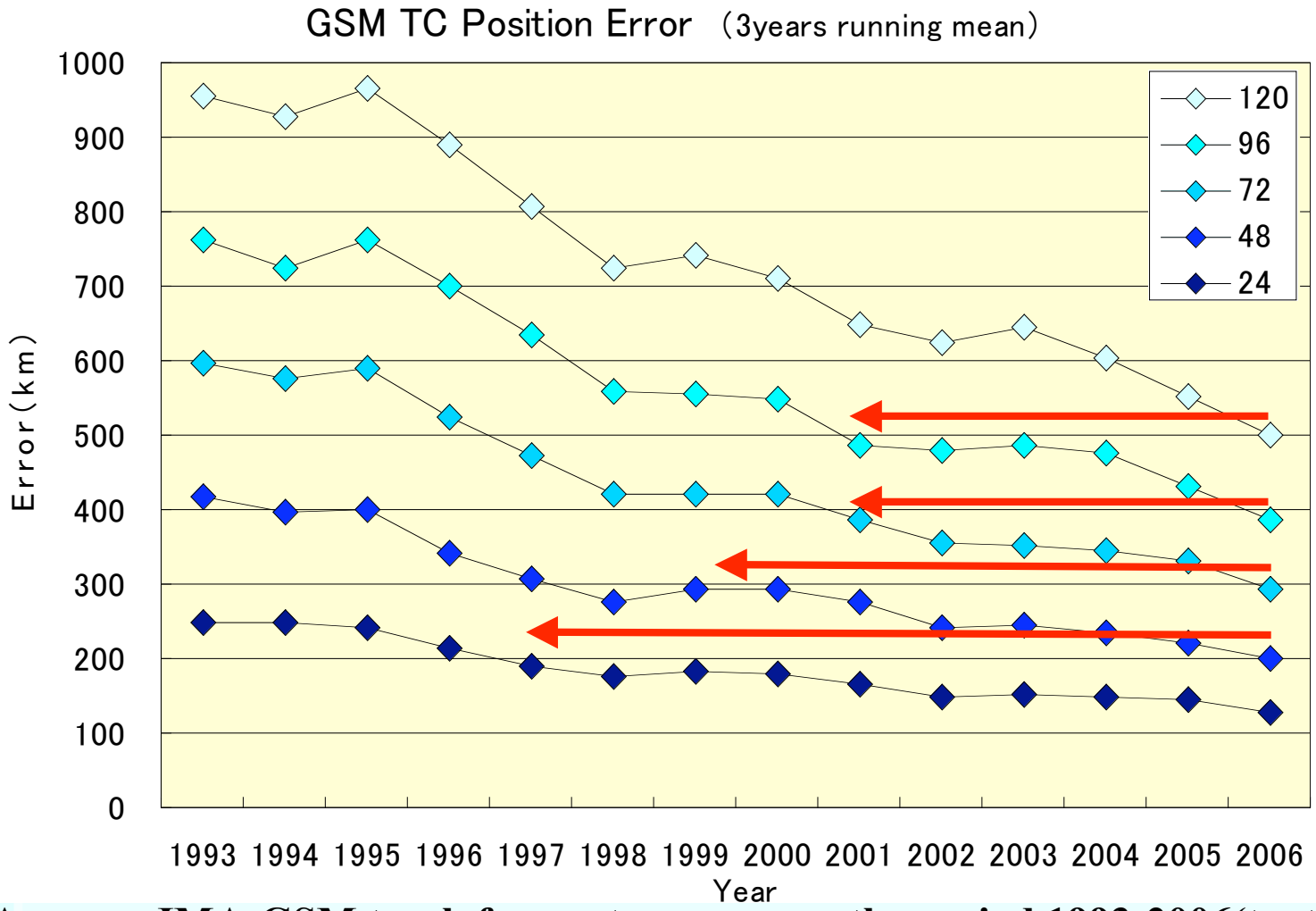
Contents

1. Introduction

Natural Disasters Related to Tropical Cyclone

- **Gale force wind**
- **Heavy rain**
- **Landslide disaster**
- **Urban disaster**
- **High tide water**
- **Tidal wave**
- **Brine damage**
- **Tornado, Water spout**
- **Fohn phenomenon**

Verification of Track Forecast of Tropical Cyclone

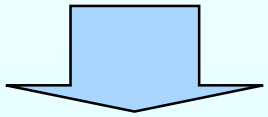


Average JMA-GSM track forecast errors over the period 1993-2006(tentative) for the western North Pacific basin. Three years running mean errors are shown for 1 – 5 day forecasts.

courtesy of R.Sakai

Difficulties of Verification of Tropical Cyclone

- **Small samples**
- **Seasonal dependency, Annual variation**
- **Regional difference**
- **Variety of structure and intensity**



> Need to survey the performance of TC forecasts over the long term to verify the systematic error

2. Forecast Tracks and Systematic Position Error Verification

- WGNE Tropical Cyclone Intercomparison Project -

Purpose: To verify operational NWP models to understand the statistical error characteristics, e.g. systematic biases, random biases, and to confirm the comprehensive improvements of NWP system related to model, assimilation and new observation data.

Benefit: Intercomparison of TC forecasts operated by multi-centers for long time shows us the natural variation and model improvement implemented at each NWP center separately.

History of WGNE Tropical Cyclone Intercomparison Project

1991 : It started by 3 NWP centres; **ECMWF**, **UKMO** and **JMA**. Verification area is ***western North Pacific*** area.

1994 : **CMC** joined

1999 : Verification of ***North Atlantic*** area started

2000 : **DWD** joined
Verification of ***eastern North Pacific*** area started

2002 : Verification of ***Southern Hemisphere***, ***North Indian Ocean*** and ***Central Pacific*** areas started

2003 : **NCEP** and **BoM** joined.
A web site for WGNE TC intercomparison project was released.

2004 : **Meteo France** and **CMA** joined.

Procedure of WGNE TC Comparison

JMA → Anouncement → **NWP Centers**

MSLP data in GPV ←

NWP Centers: BoM, CMA, CMC, DWD, ECMWF, Meteo France, NCEP, UKMO and JMA

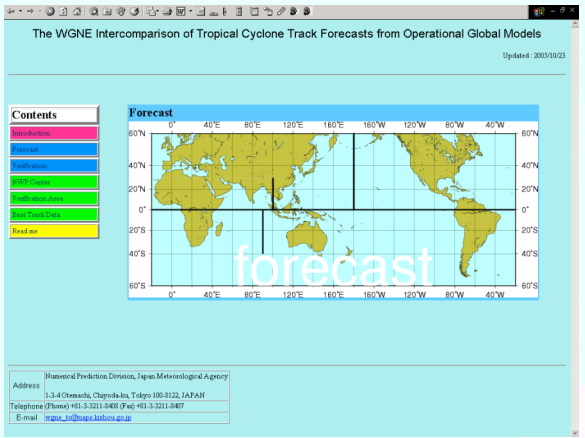
TC Tracking
Center pressure

RSMCs, TCWCs, and JTWC → Best Track data →

RSMC-Tokyo, Miami, New Deli, La Reunion, TCWC-Perth, Darwin, Brisbane, Welington and JTWC

Statistics

Upload the results
on a web site
at JMA for WGNE
Report to WGNE meeting



NWP Centers Data List (2005)

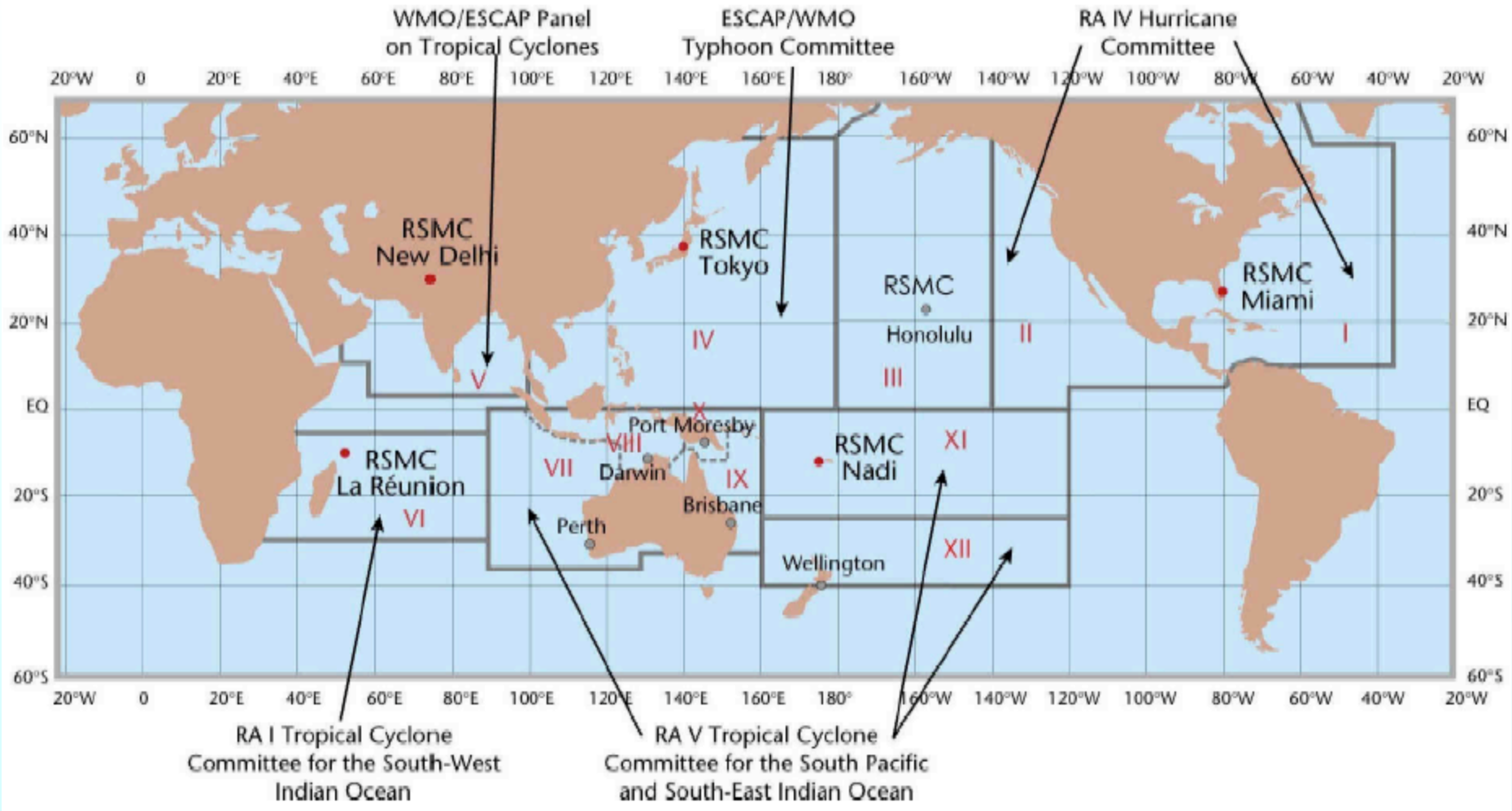
NWP Centers	*Participat e Year*	*Bogus Data*	*Horizontal Res. of provided data*	*Model Res. as of 2005*
BoM	2003	Not used	0.75°x 0.75°	TL239L29 =>TL239L33
CMC	1994	Not used	1.0°x 1.0°	0.9°x 0.9°L28
DWD	2000	Not used	0.5°x 0.5°	40km L40
ECMWF	1991	Not used	0.5°x 0.5°	TL511 L60
JMA	1991	Used in WNP area	1.25°x 1.25°	TL319 L40
METEO FRANCE*1	2004	Used*2	0.5°x 0.5°	TL358(C2.4)L41
NCEP	2003	Used in the rare cases*3	1.0°x 1.0°	T254 L64 => T382 L64
UKMO	1991	Used	0.8333°x 0.5555° => 0.5625°x 0.375° (from 13th Dec. 2005)	0.8333°x 0.5555°L38 => 0.5625°x 0.375°L50

*1 METEO FRANCE data is up to T+72hr, others are at least up to T+120hr.

*2 except for south Pacific and North Indian ocean

*3 when the storm is not found in the first guess

Best Track Providers



Regional Specialized Meteorological Centers,
Tropical Cyclone Warning Centers, and
US Joint Typhoon Warning Center

Target of WGNE TC Intercomparison

Tropical Cyclone Classifications (all winds are 10-minute averages)

Beaufort scale	10-minute sustained winds (knots)	N Indian Ocean IMD	SW Indian Ocean MF	Australia BOM	SW Pacific FMS	NW Pacific JMA	NW Pacific JTWC	NE Pacific & N Atlantic NHC & CPHC
0–6	<28	Depression	Tropical Disturbance	Tropical Low	Tropical Depression	Tropical Depression	Tropical Depression	Tropical Depression
7	28-29	Deep Depression	Tropical Depression					
	30-33							
8–9	34–47	Cyclonic Storm	Moderate Tropical Storm	Tropical Cyclone (1)		Tropical Storm	Tropical Storm	Tropical Storm
10	48–55	Severe Cyclonic Storm	Severe Tropical Storm	Tropical Cyclone (2)		Severe Tropical Storm		
11	56–63							Hurricane (1)
	64–72			Severe Tropical Cyclone (3)				
	73–85		Tropical Cyclone		Tropical Cyclone			Hurricane (2)
	86–89	Very Severe Cyclonic Storm		Severe Tropical Cyclone (4)			Typhoon	Major Hurricane (3)
12	90–99		Intense Tropical Cyclone			Typhoon		
	100–106							Major Hurricane (4)
	107-114							
	115–119		Very Intense Tropical Cyclone	Severe Tropical Cyclone (5)			Super Typhoon	Major Hurricane (5)
	>120	Super Cyclonic Storm						

Best Track Data & Tracking Method

Best track data

Verification area	*Best track data*	*TC cases in 2005*
Western North Pacific	RSMC - Tokyo	23 (29 in 2004)
North Atlantic	RSMC - Miami	28 (15 in 2004)
Eastern North Pacific*1	RSMC - Miami	15 (12 in 2004)
North Indian Ocean	RSMC - New Deli	4 (4 in 2004)
South Indian Ocean	RSMC – La Reunion	Not yet arrived
South Hemisphere w/o South Indian Ocean	TCWC Perth, Darwin, Brisbane Wellington and JTWC	10 (14 in 2004)

*1 : The verification for eastern North Pacific includes it for Central Pacific.

Tracking method

local pressure minimum;

1. First position: search from the best track position
2. Second position: search from the first position
3. Third and after: search from estimated position from the latest two positions

Verification Parameters

- **Forecast Error (km)**

  The distance between the best track position and the forecast position

- **Detection Rate (%)**

  Detection Rate (*t*) = A / B (*t*; forecast time)

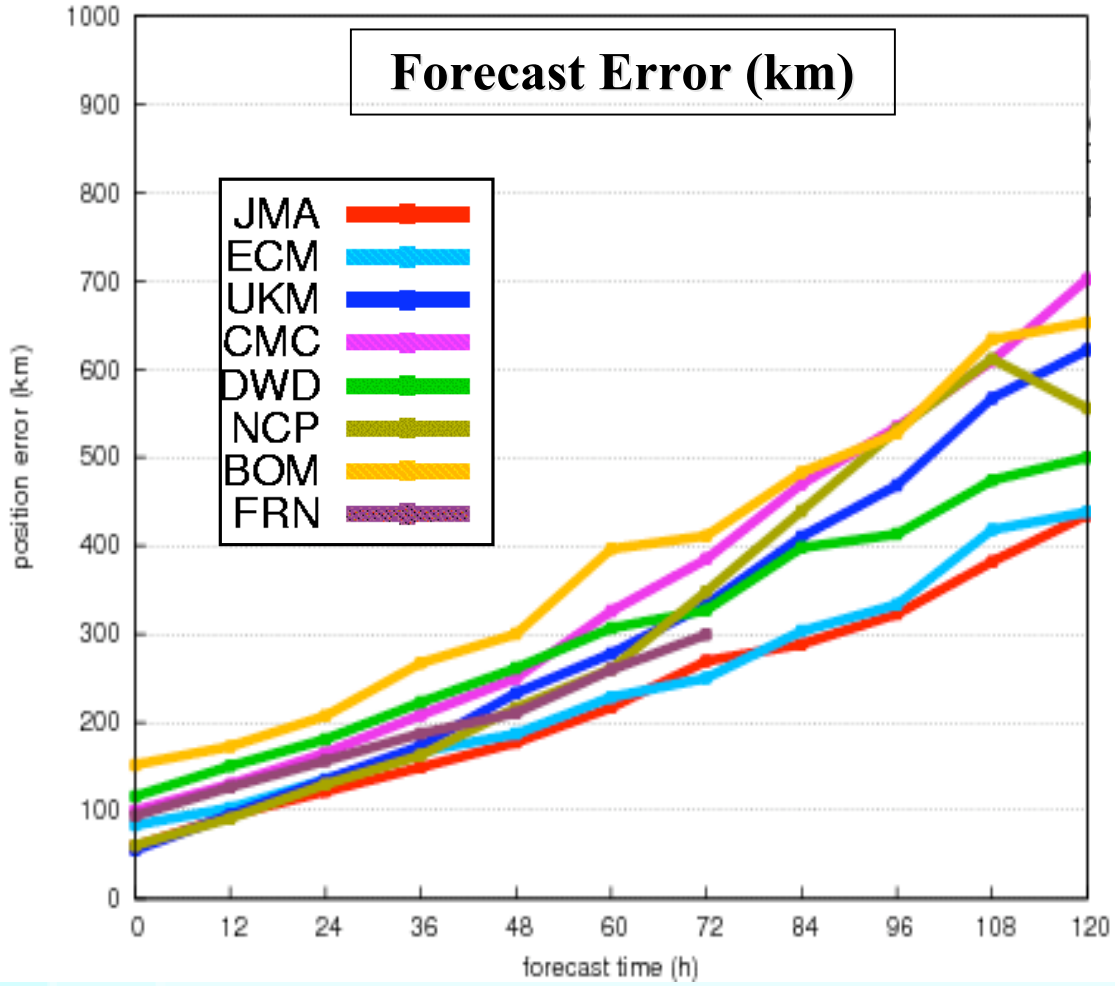
  A: The number of initial times as a TC is analyzed at forecast time *t* and a NWP model tracks the TC at forecast time *t*.

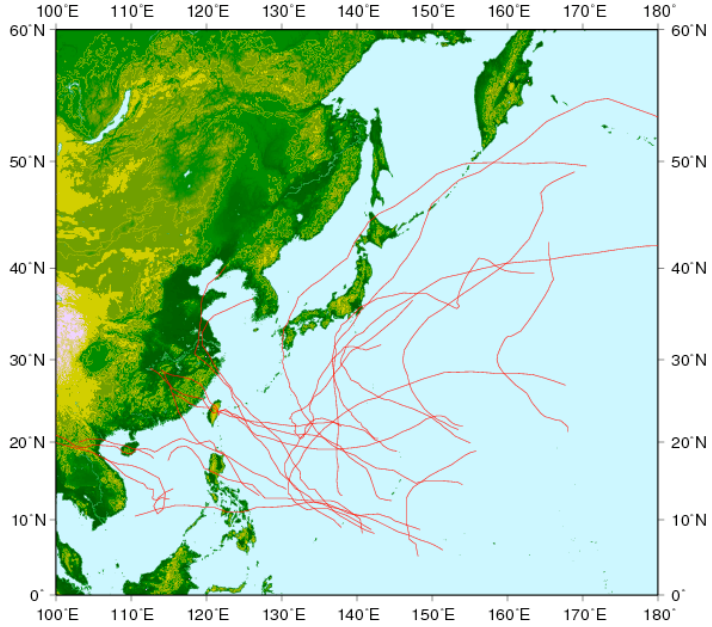
  B: The number of initial times as a TC is analyzed at forecast time *t*.

Verification using both parameters is important for comparison with inhomogeneous sample.

Verification of western North Pacific area

- 23 TC cases in 2005 -





Verification of western North Pacific area

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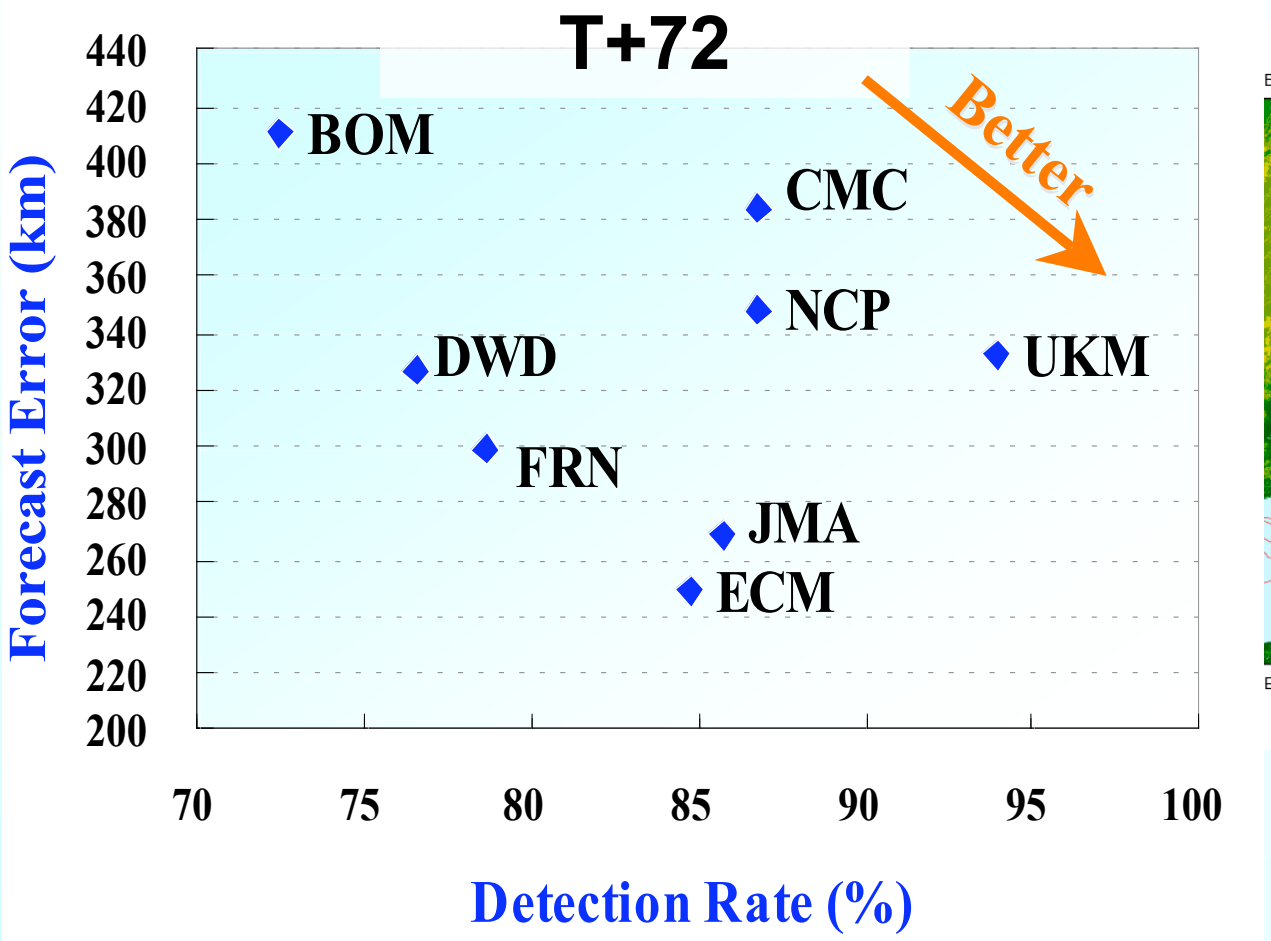
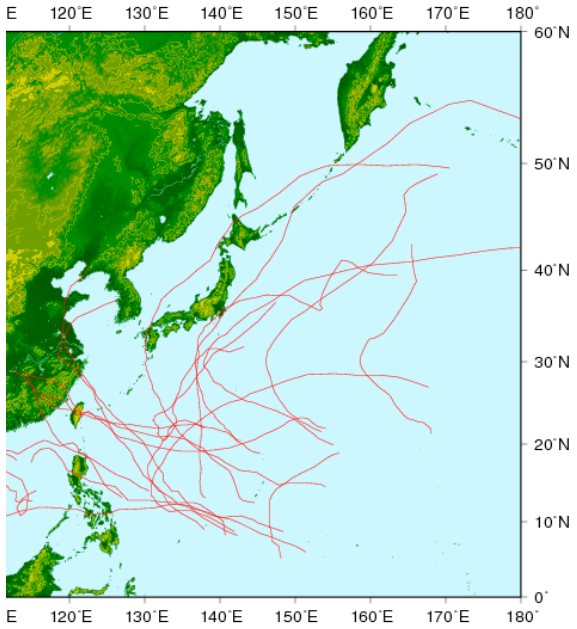
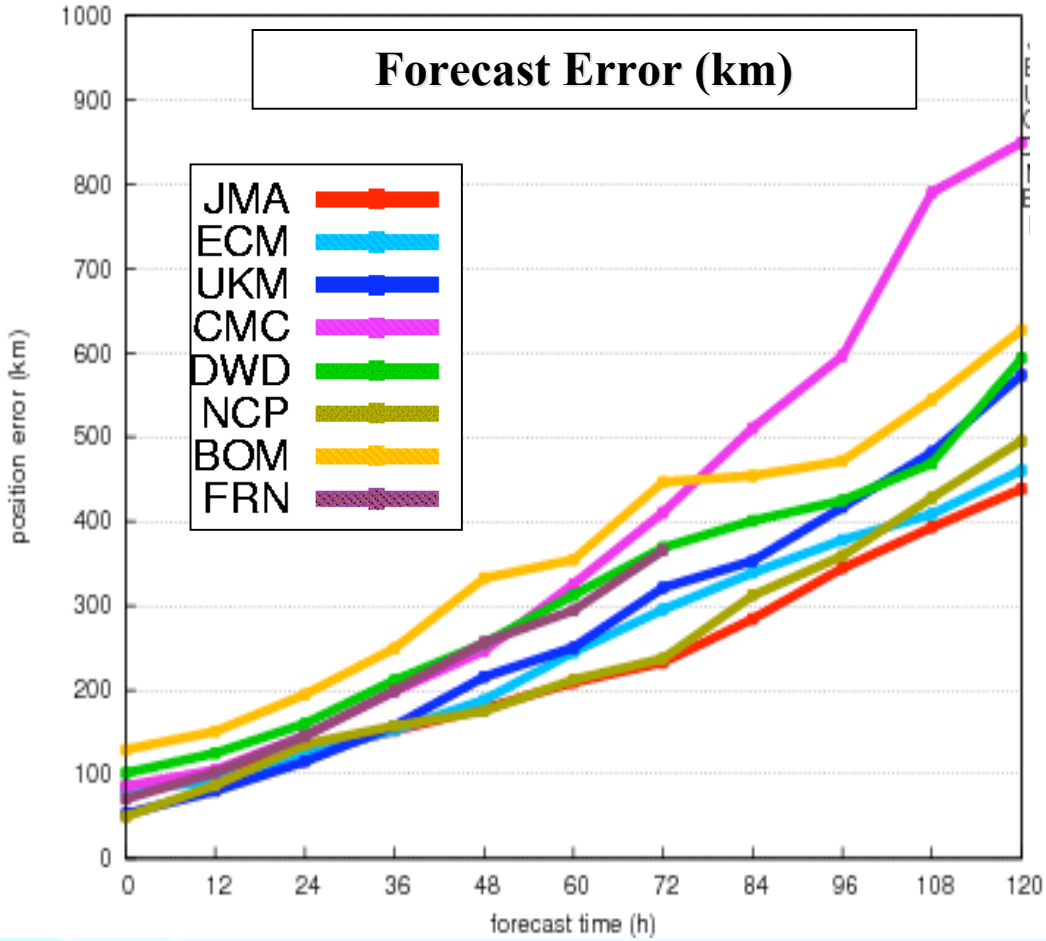
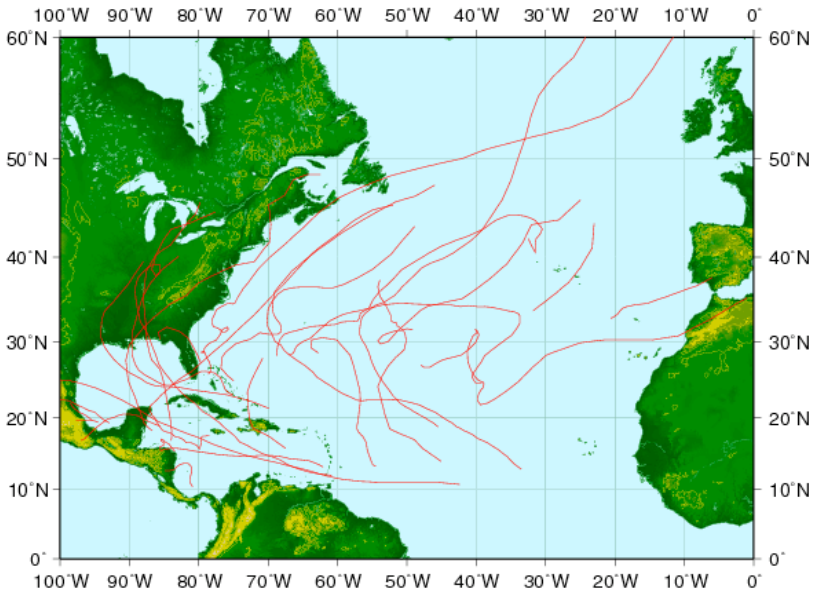




Verification of North Atlantic area

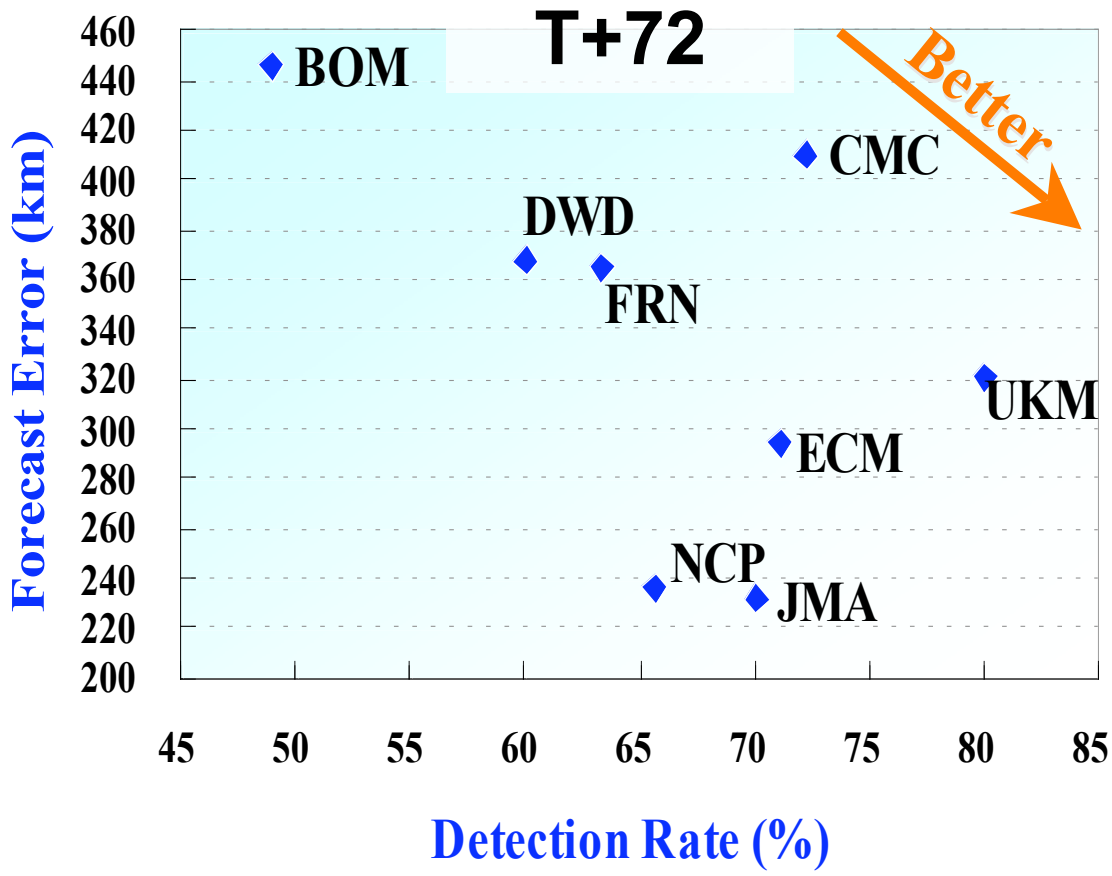
- 28 TC cases in 2005 -

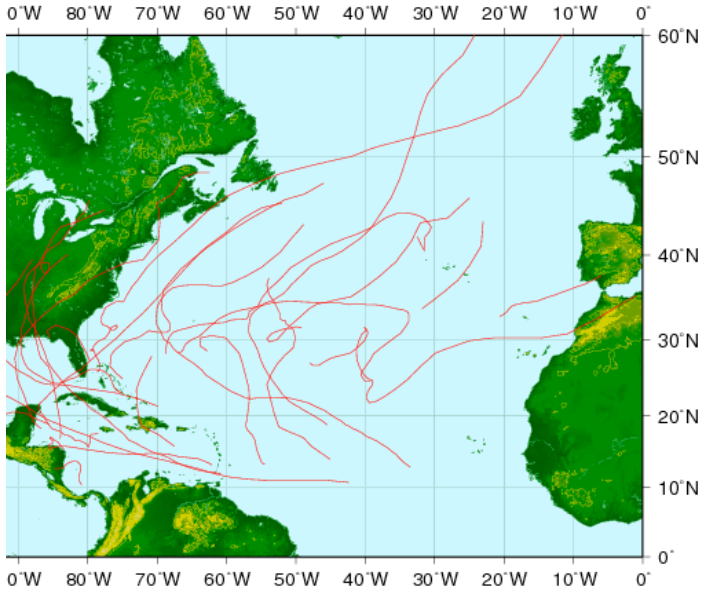




Verification of North Atlantic area

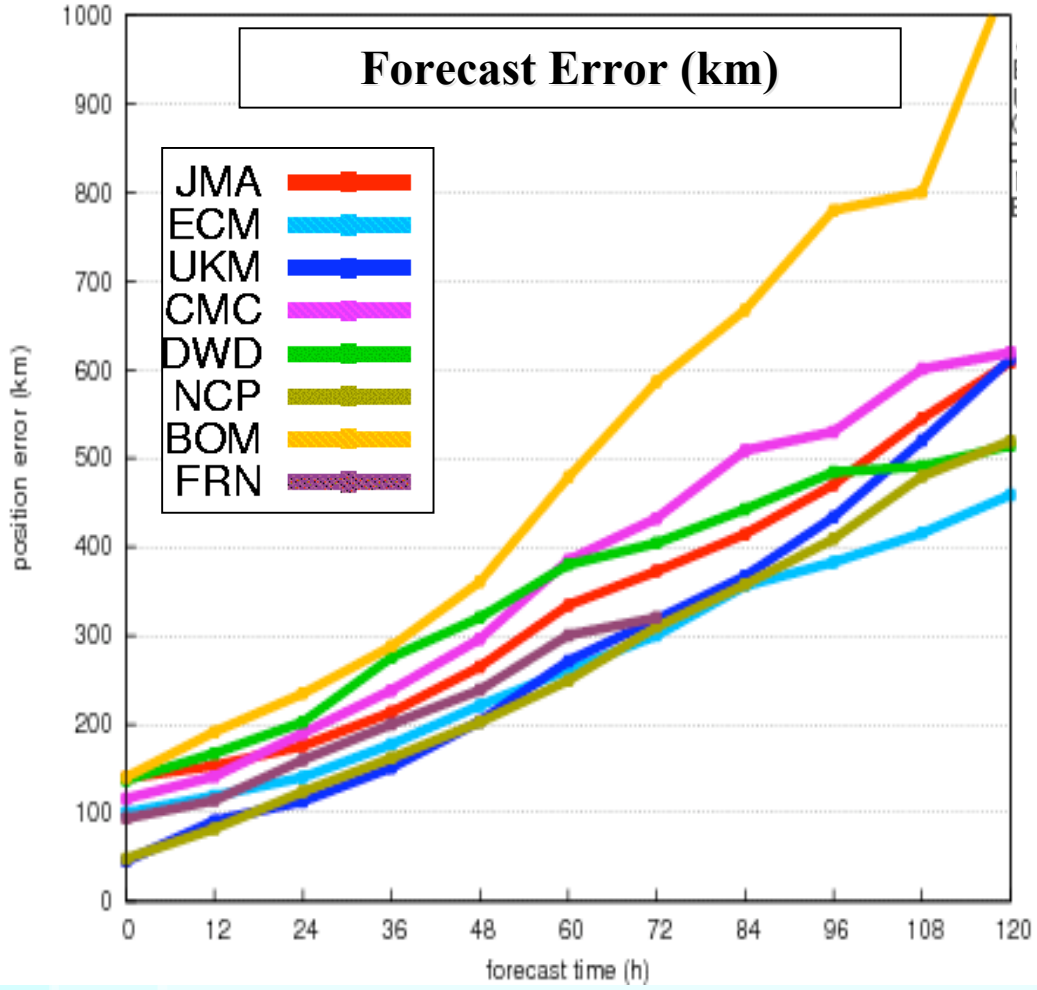
- 28 TC cases in 2005 -

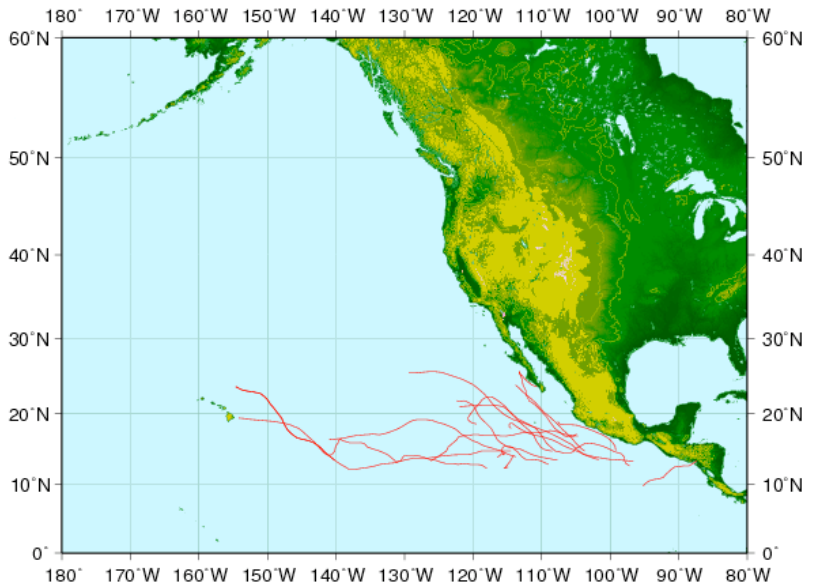




Verification of eastern North Pacific area

- 15 TC cases in 2005 -





Verification of eastern North Pacific area

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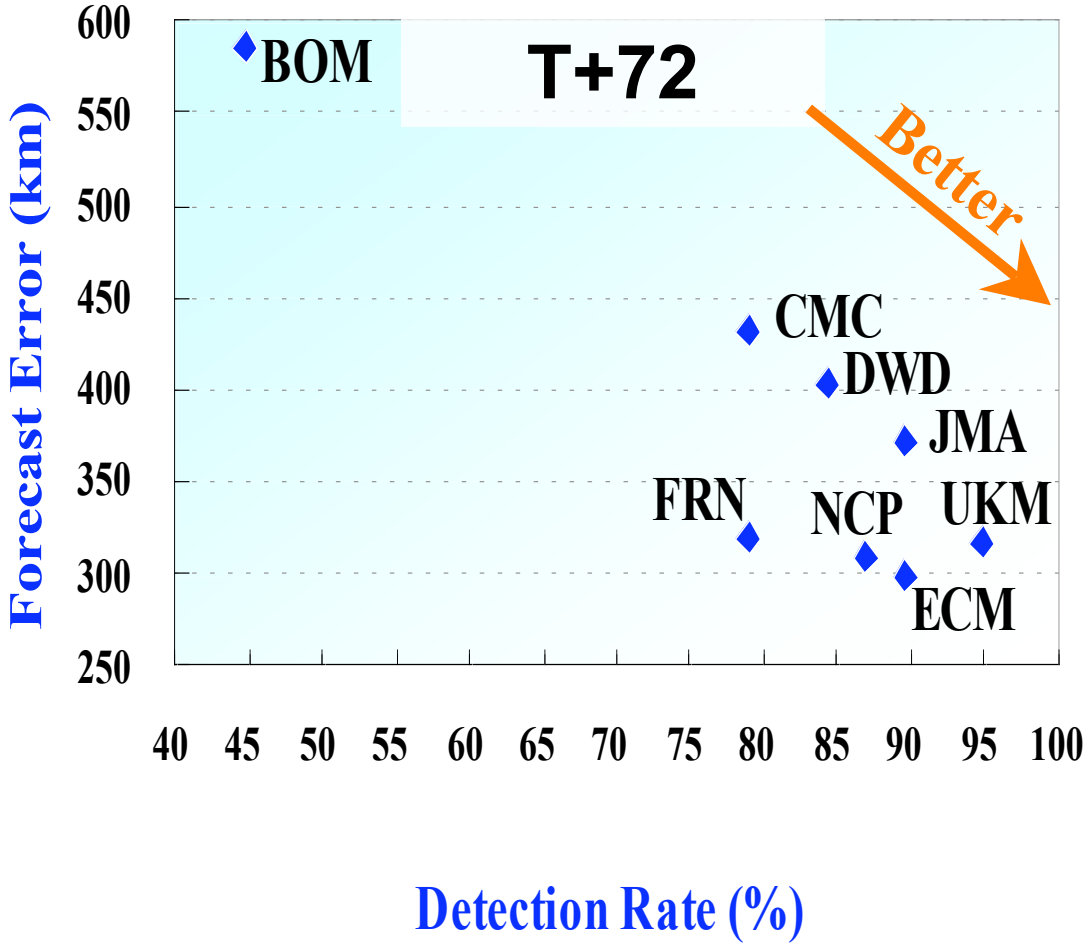
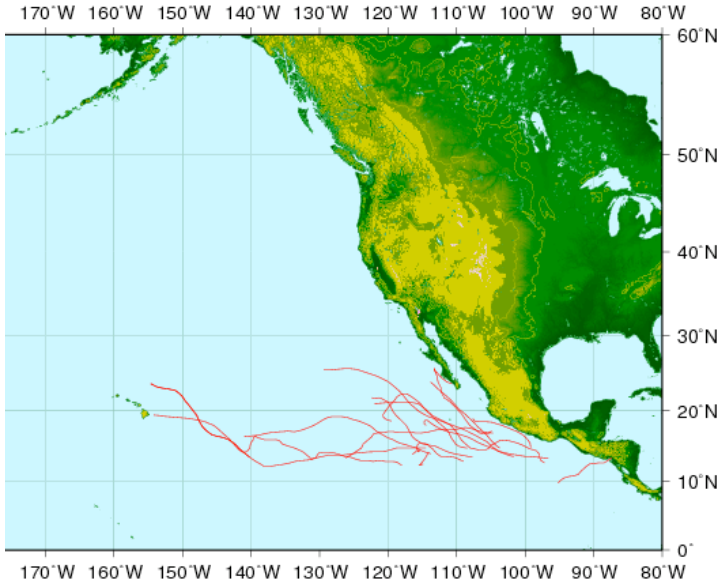
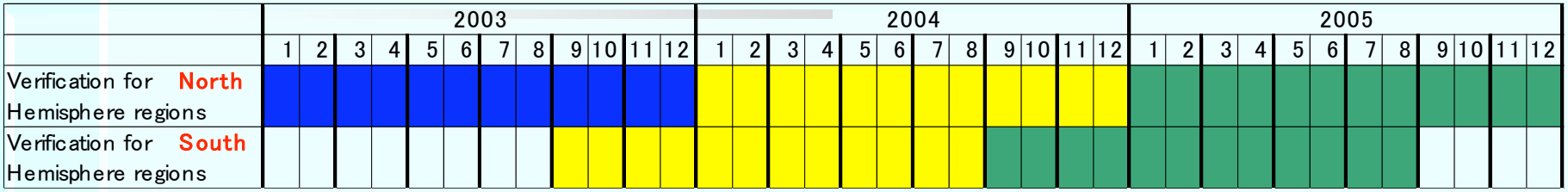




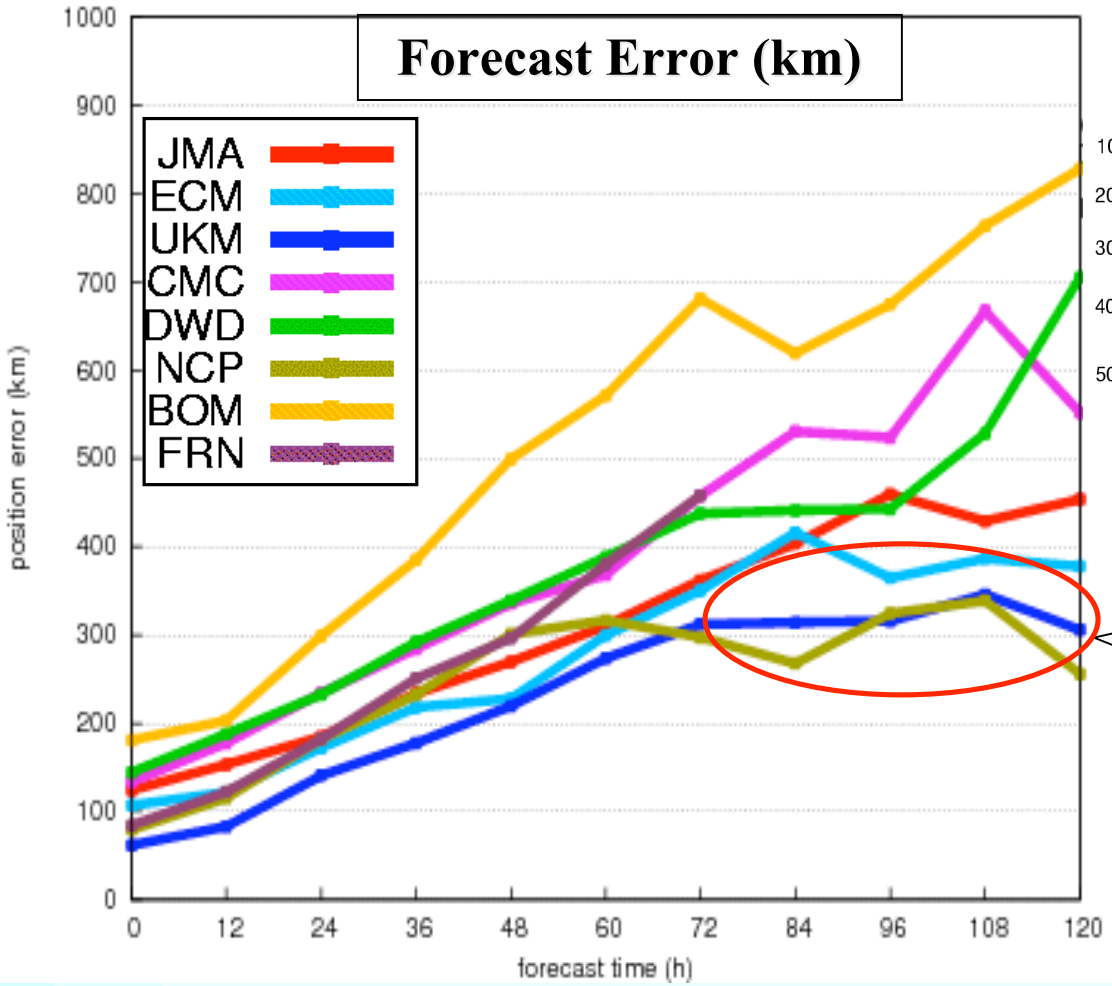
The verification for Southern Hemisphere

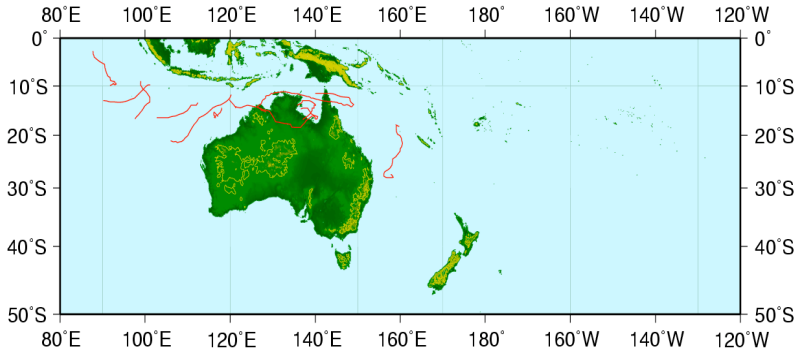
The TCs season in Southern Hemisphere is different from that in other verification areas in Northern Hemisphere. Therefore the verification of Southern Hemisphere regions for 2005 has been done against TCs which are generated from 2004/09/01 to 2005/08/31.



Verification of South Pacific and South-East Indian Ocean area

- 10 TC cases in 2005 (except the data of RSMC Nadi)-



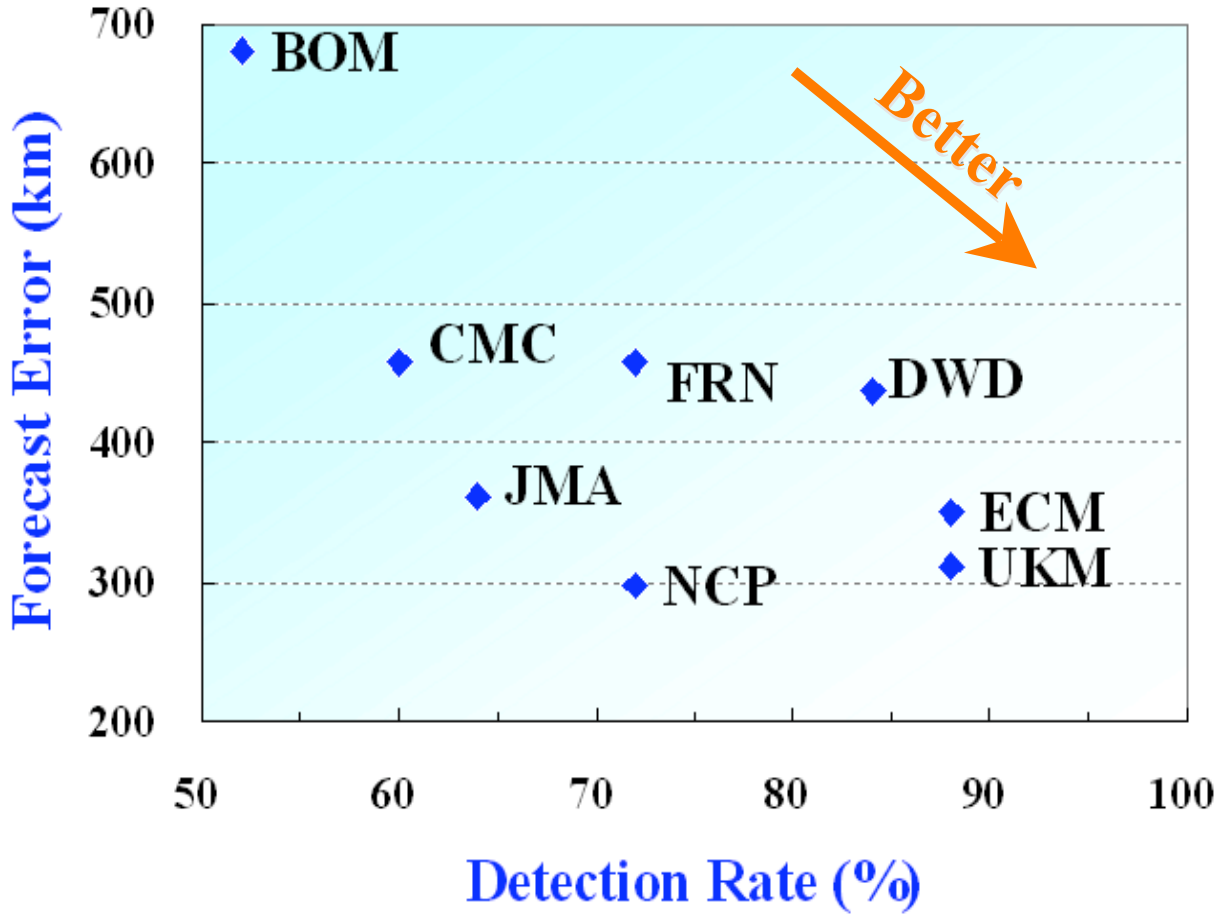


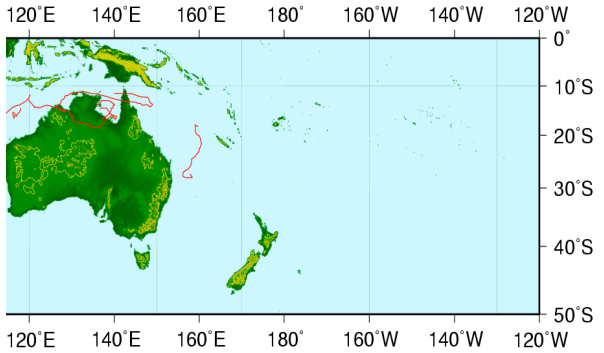
Unnatural forecast time dependency due to insufficient samples

Verification of South Pacific and South-East Indian Ocean area

- 10 TC cases in 2005 (except the data of RSMC Nadi)-

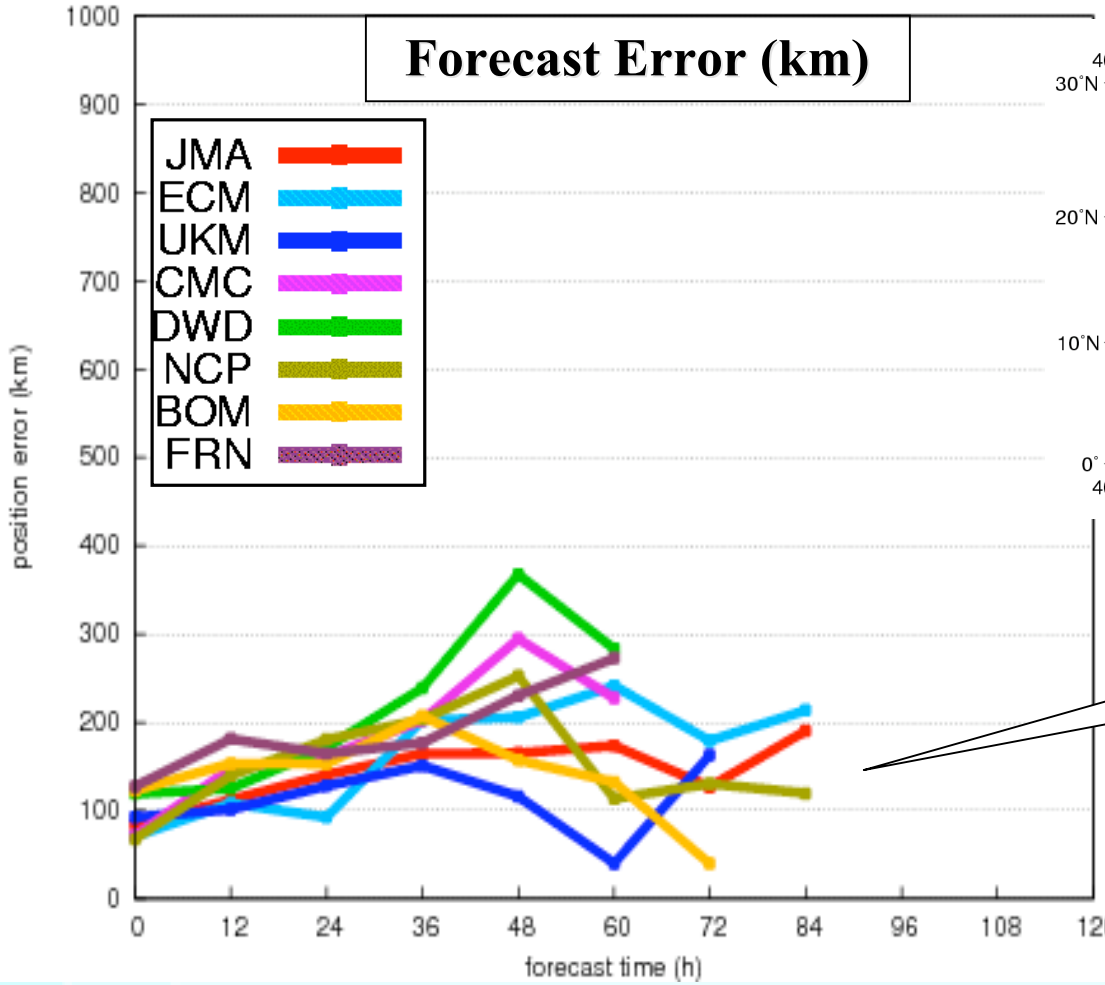
T+72

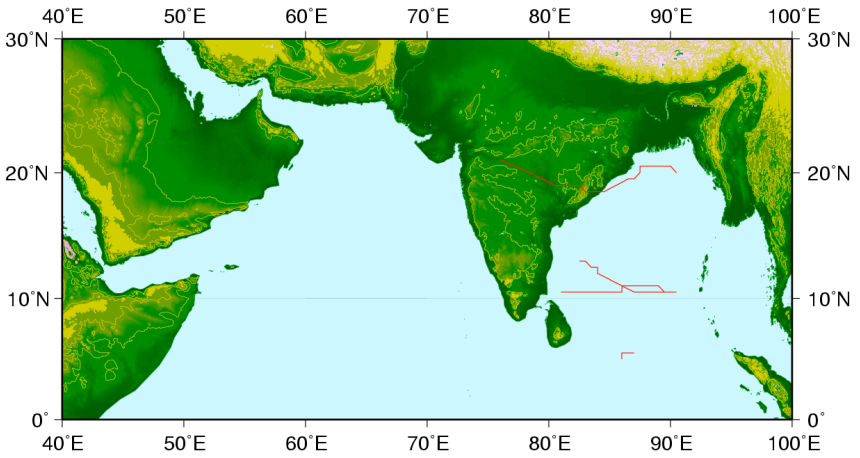




Verification of North Indian Ocean area

- 4 TC cases in 2005 -





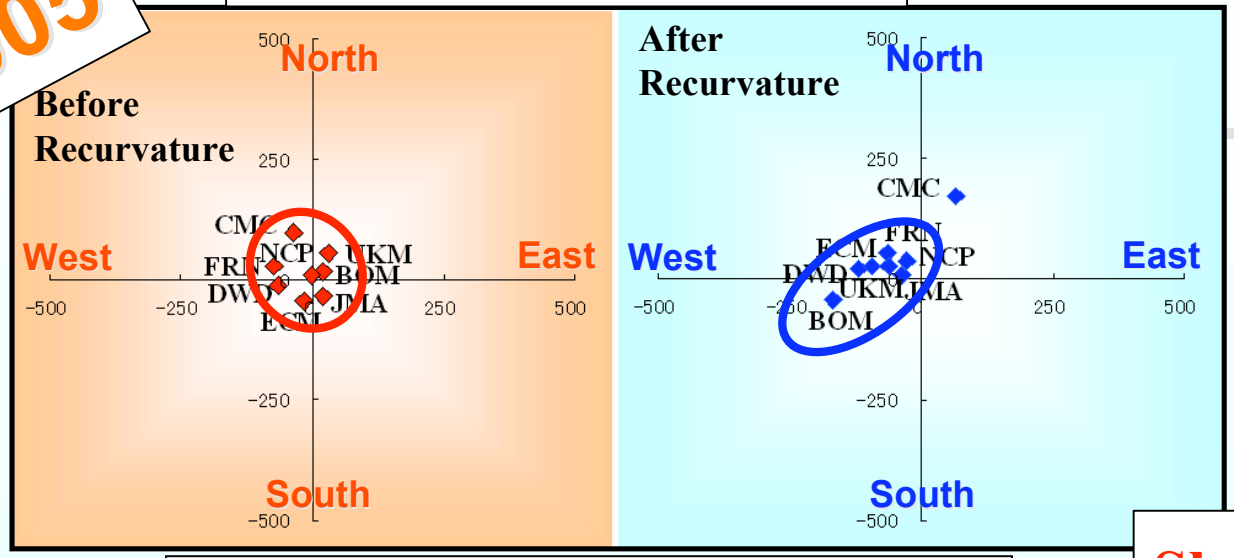
Too small samples

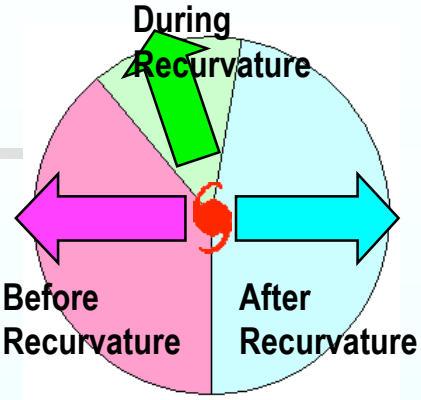
2.1 Systematic Position Error

Systematic TC Position Error against Analysis

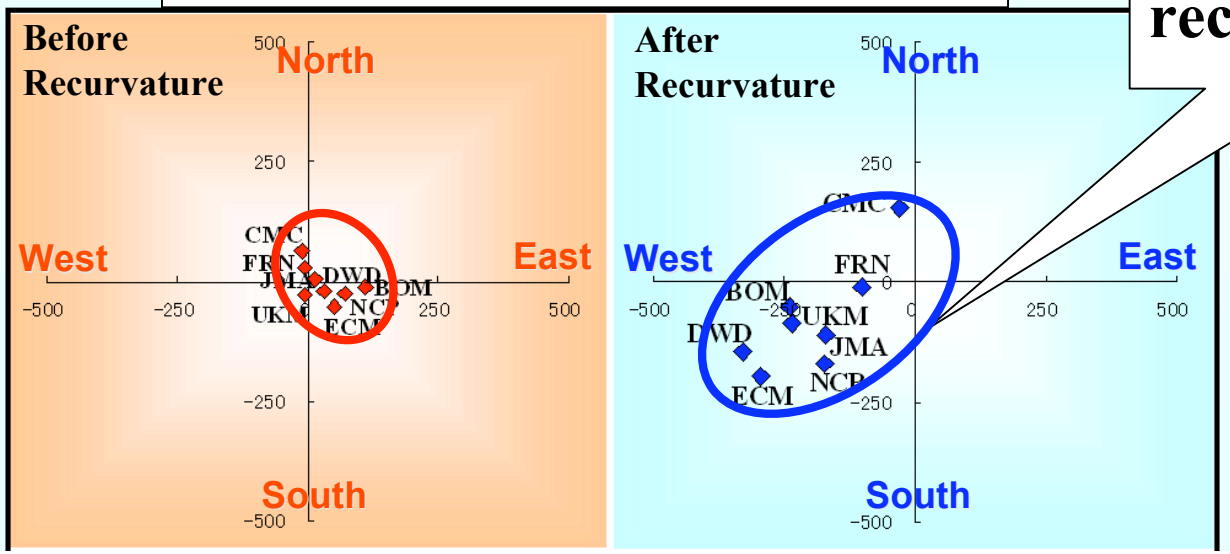
2005

- North Atlantic area 2005 -





- western North Pacific area 2005 -

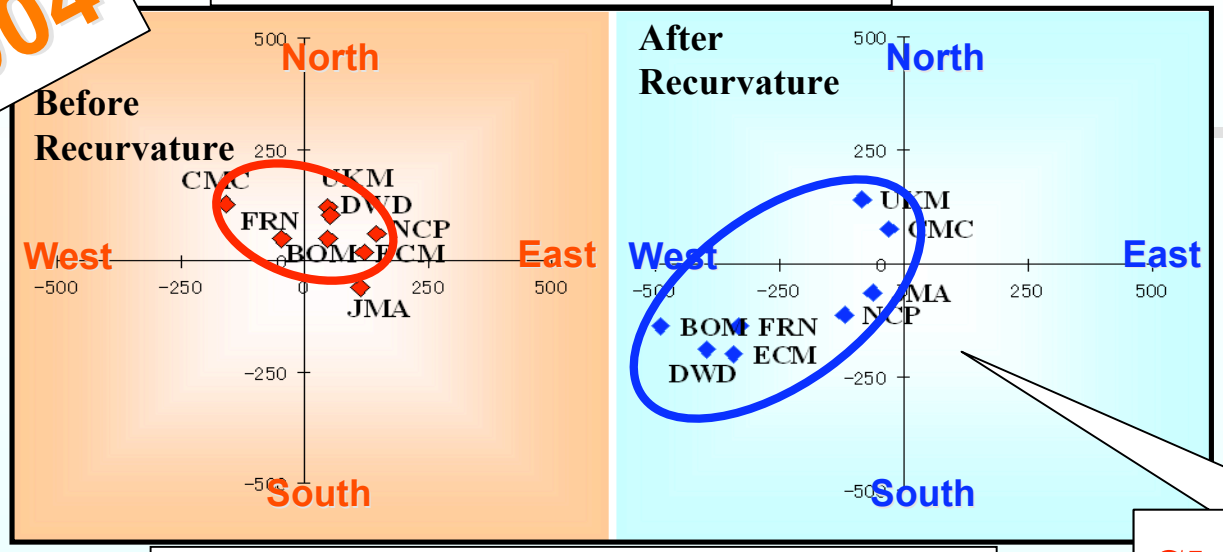


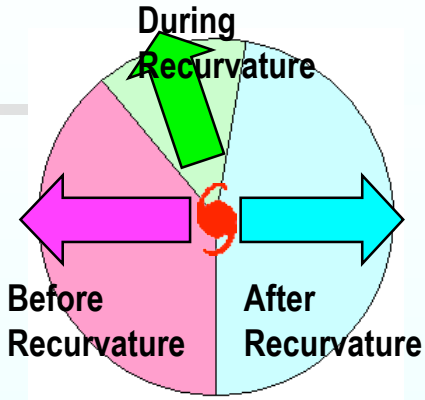
Slow bias after recurvature

Systematic TC Position Error against Analysis

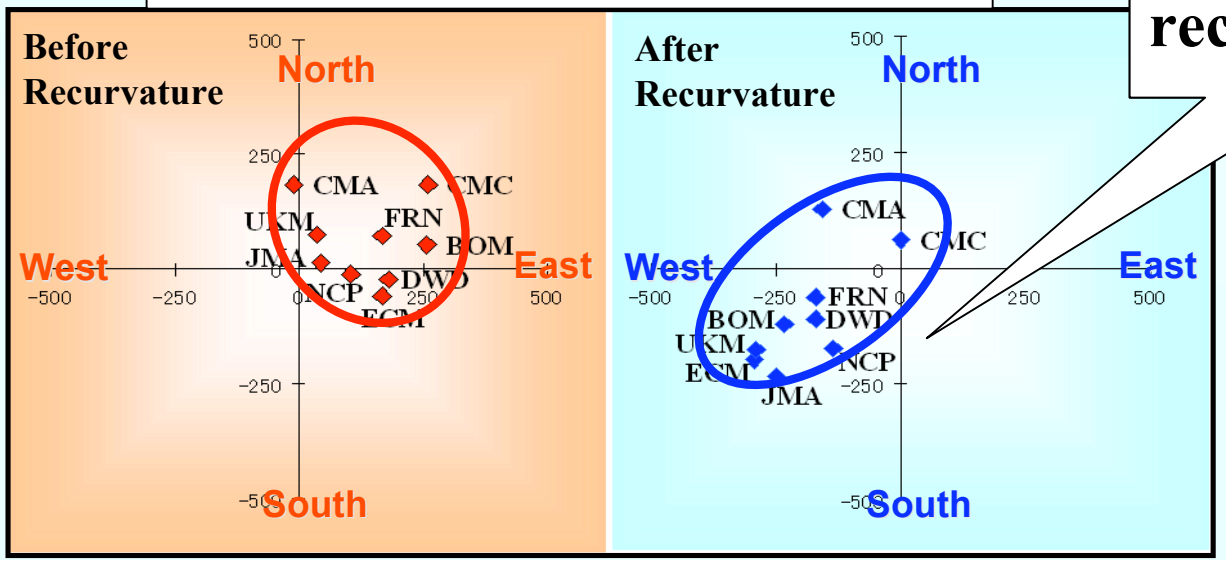
2004

- North Atlantic area 2004 -



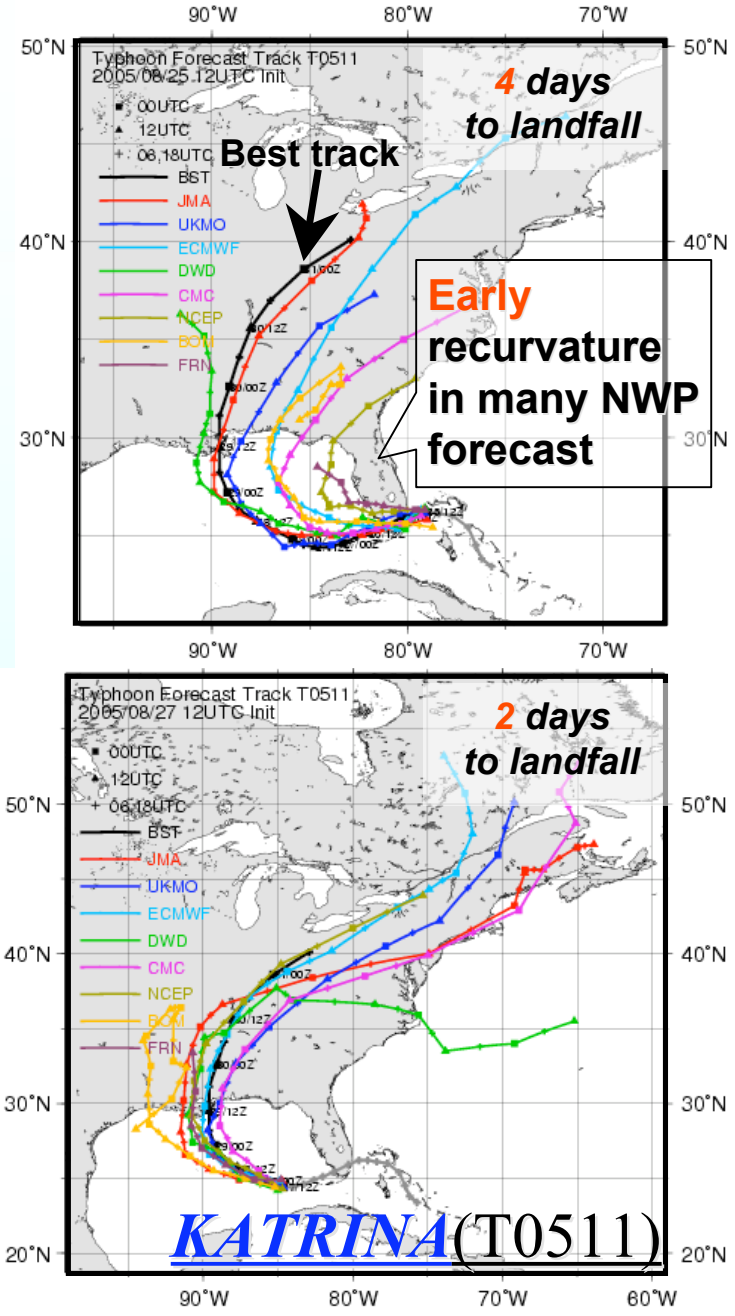


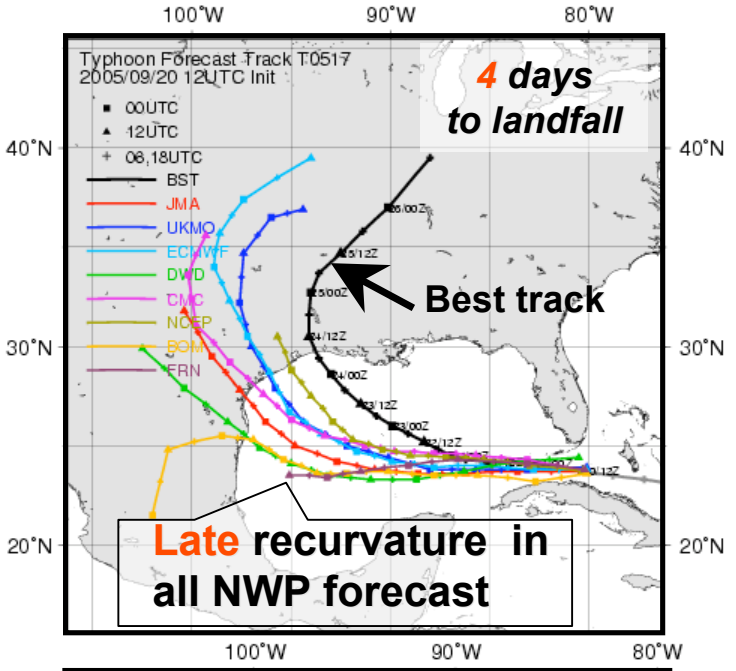
- western North Pacific area 2004 -

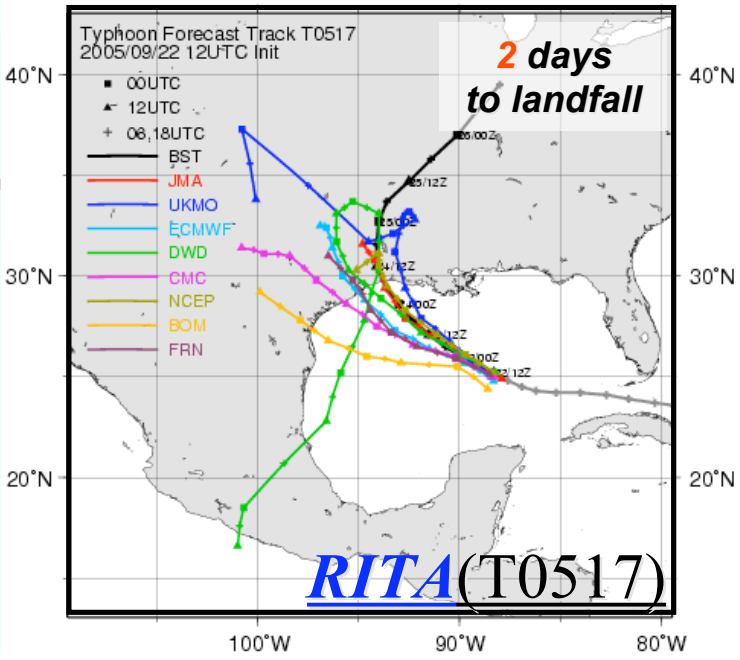


Slow bias after recurvature

Systematic Bias of Track Forecast

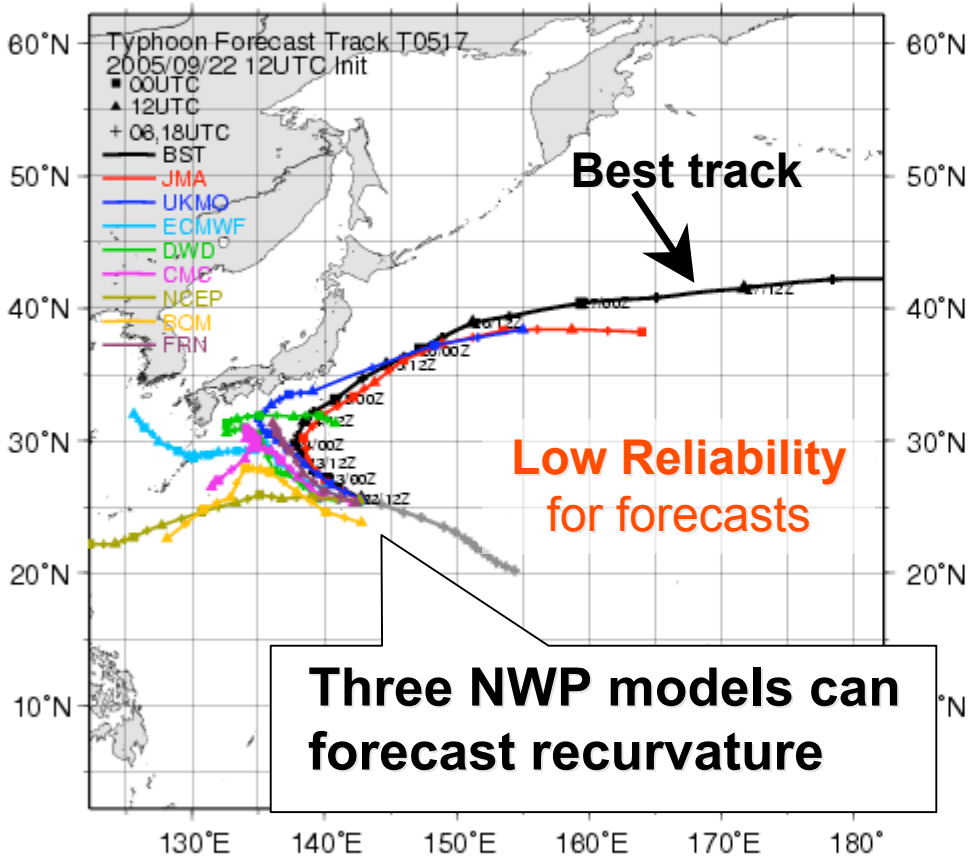


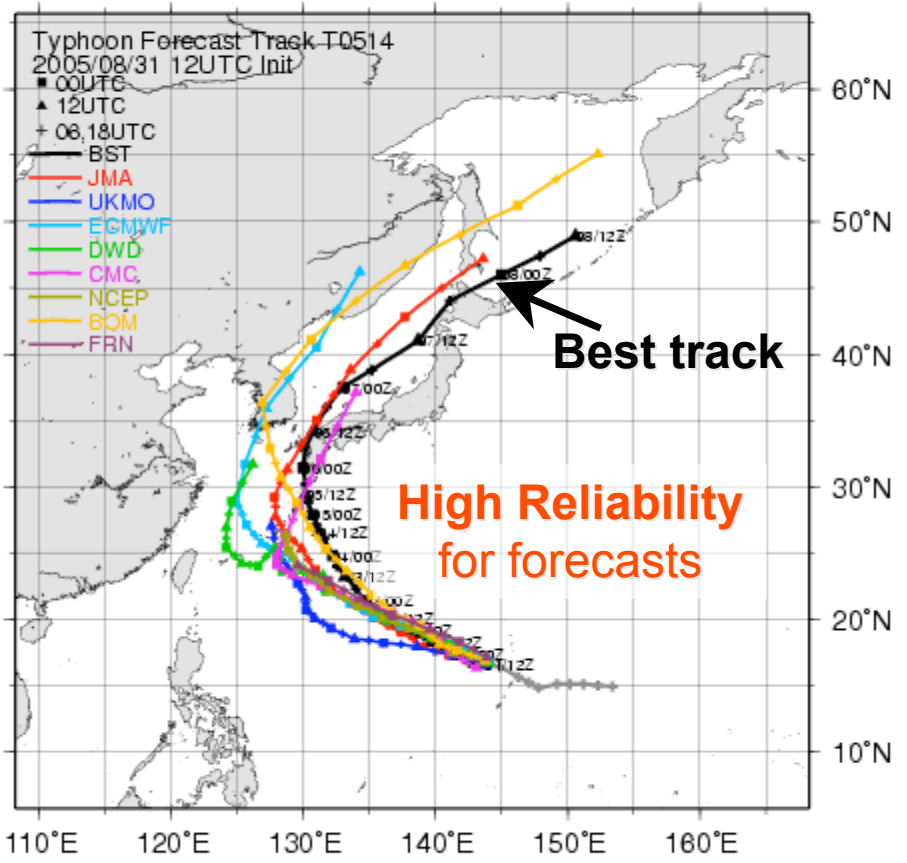




SAOLA(T0517) & *NABI*(T0514)

- western North Pacific area -

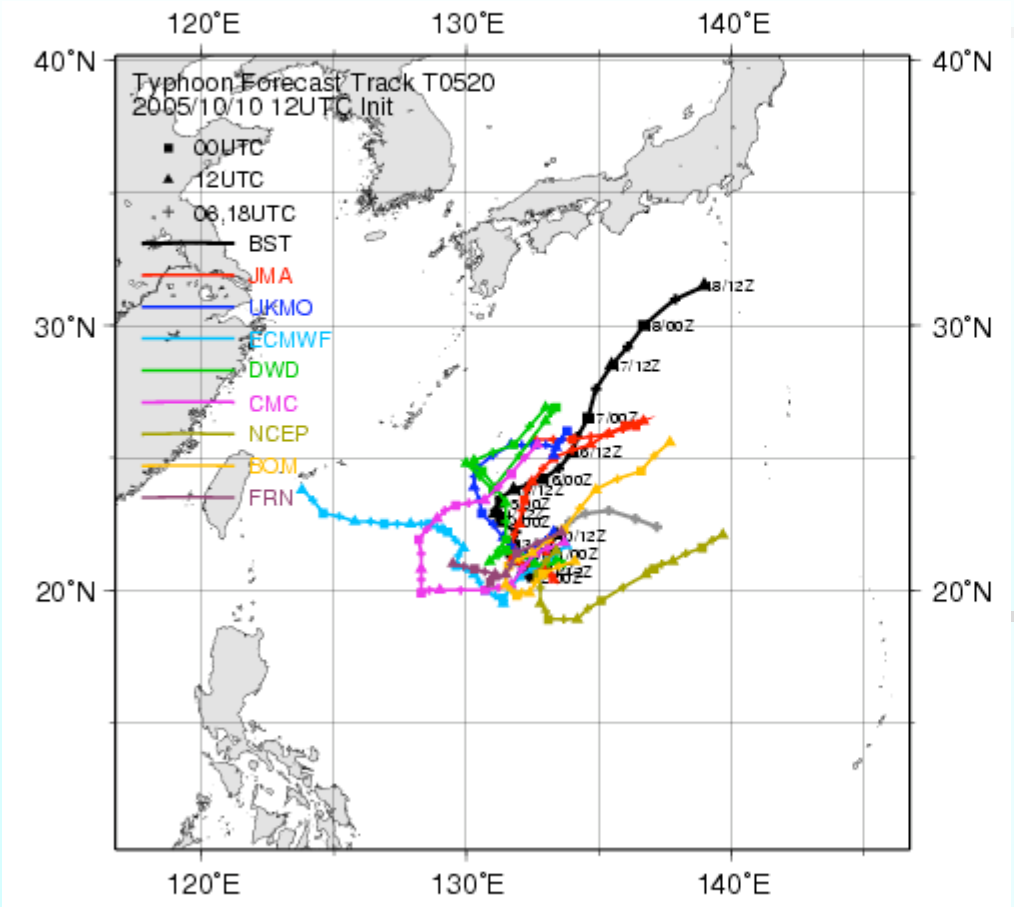




Multi-Center Ensemble forecasts can deliver a probabilistic forecast with reliability.

Uncertainty and Predictability : ***KIROGI***(T0520)

- western North Pacific area -



-Predictability **limit of deterministic** NWP forecast ?

- The importance of **Multi-Center Ensemble** prediction

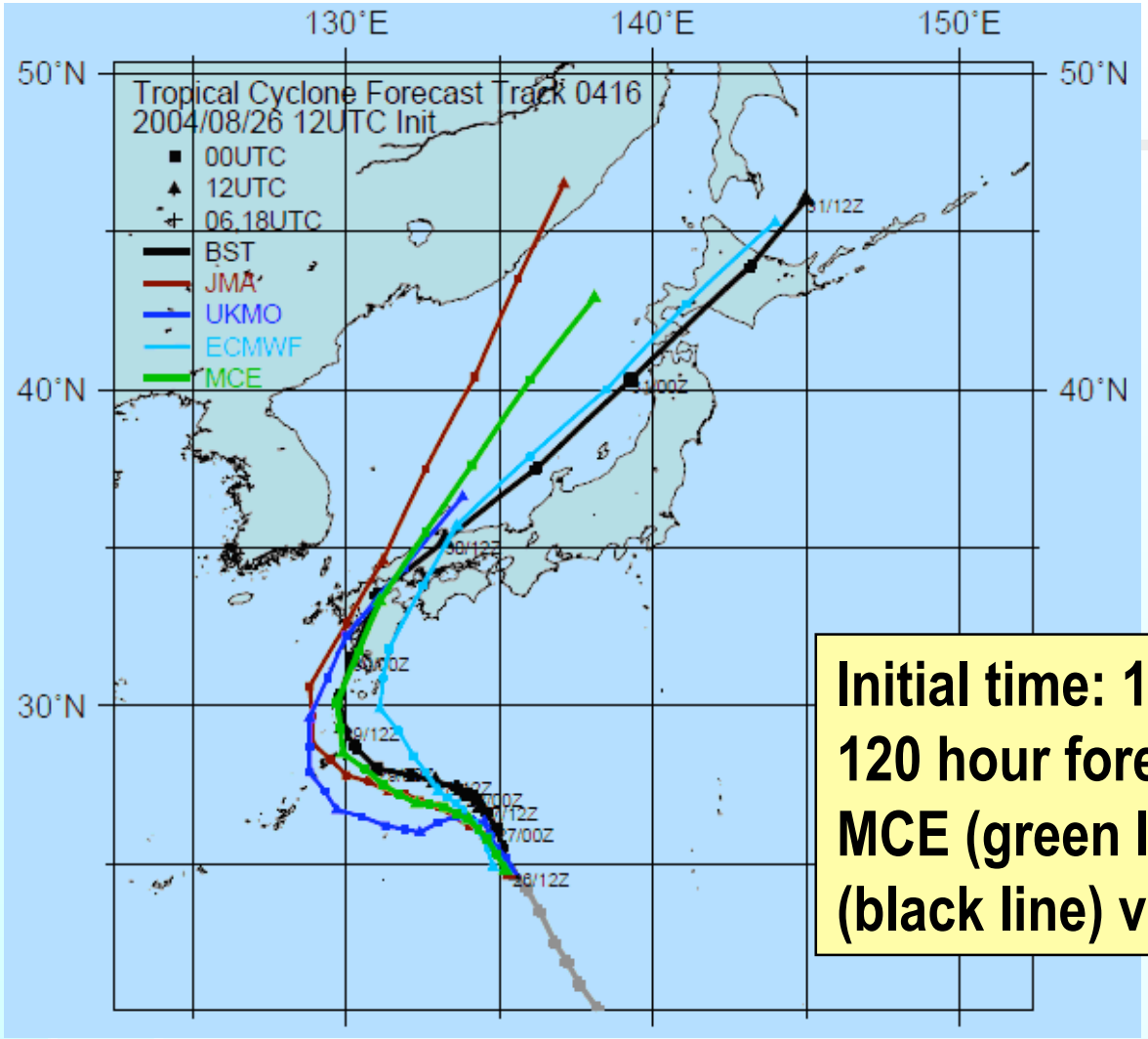
- Many works on MCE: Goerss (2000), Elsberry and Carr (2000), Krishnamurti et al. (1999), Williford et al.(2003), Vijaya Kumar et al. (2003)

- JTWC has already operated an MCE.

Successful Example of Multi-Center Ensemble

- western North Pacific area -

Yamaguchi, 2006

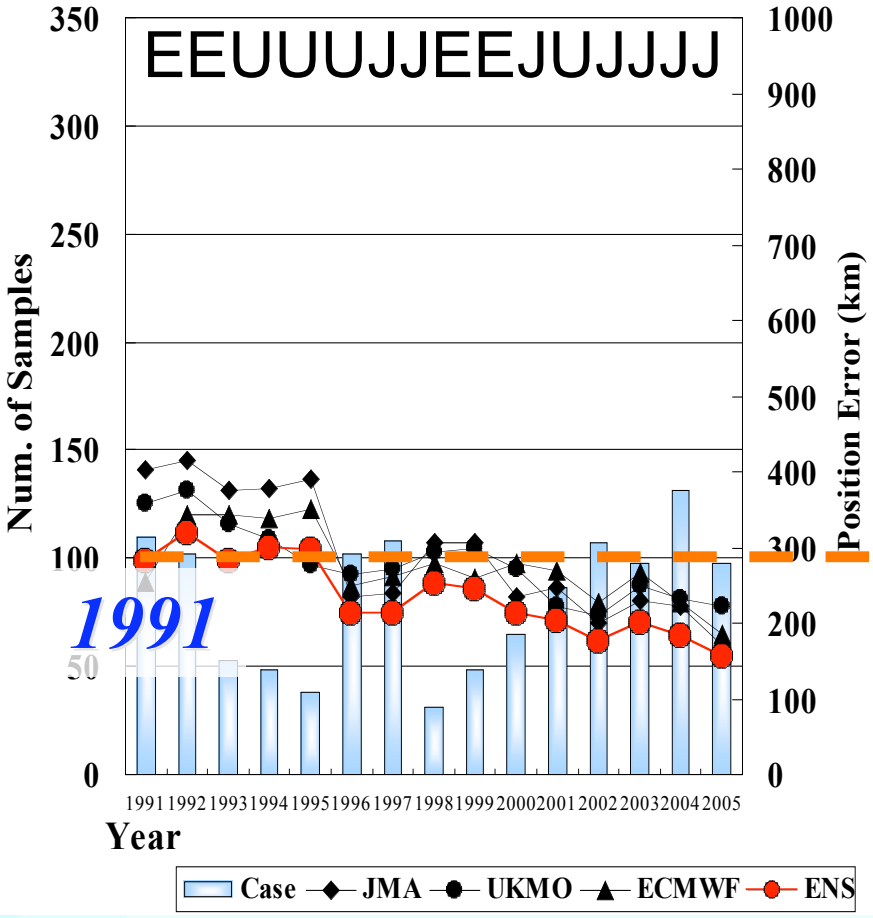


Initial time: 12UTC 26 August 2004
120 hour forecasts and best track
MCE (green line) predict the best track (black line) very well

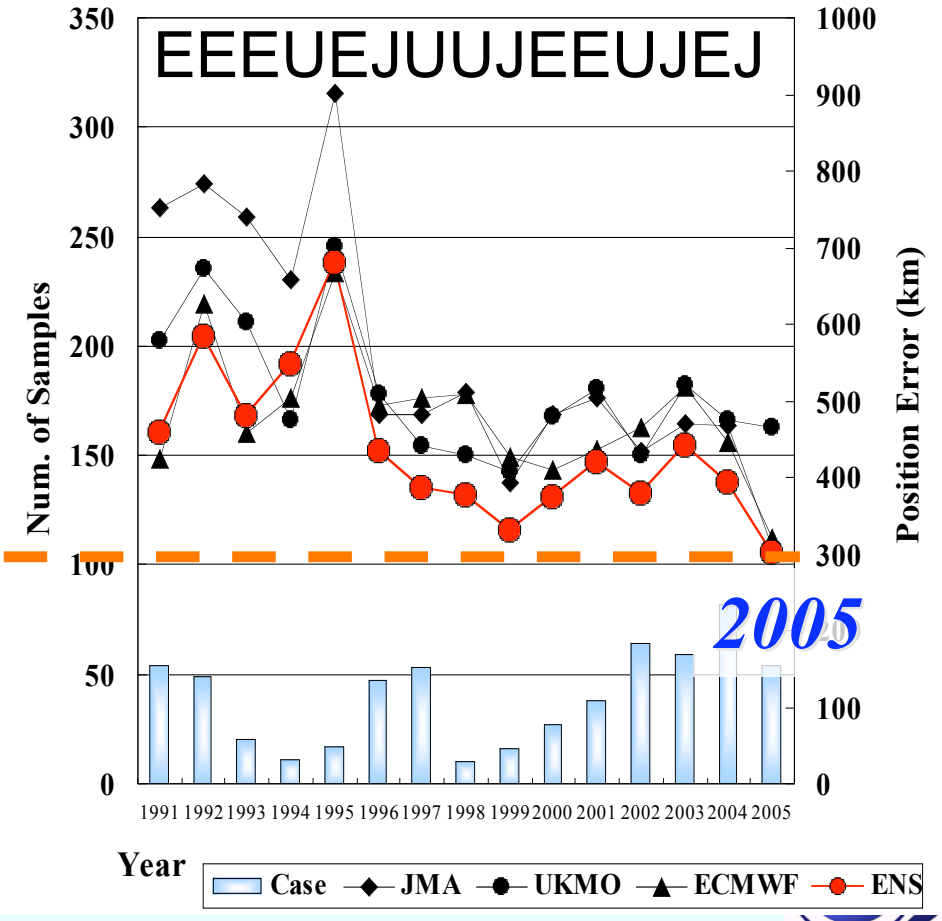
Multi-Center Ensemble (JMA, ECMWF, UKMO)

- western North Pacific area -

2day Forecast



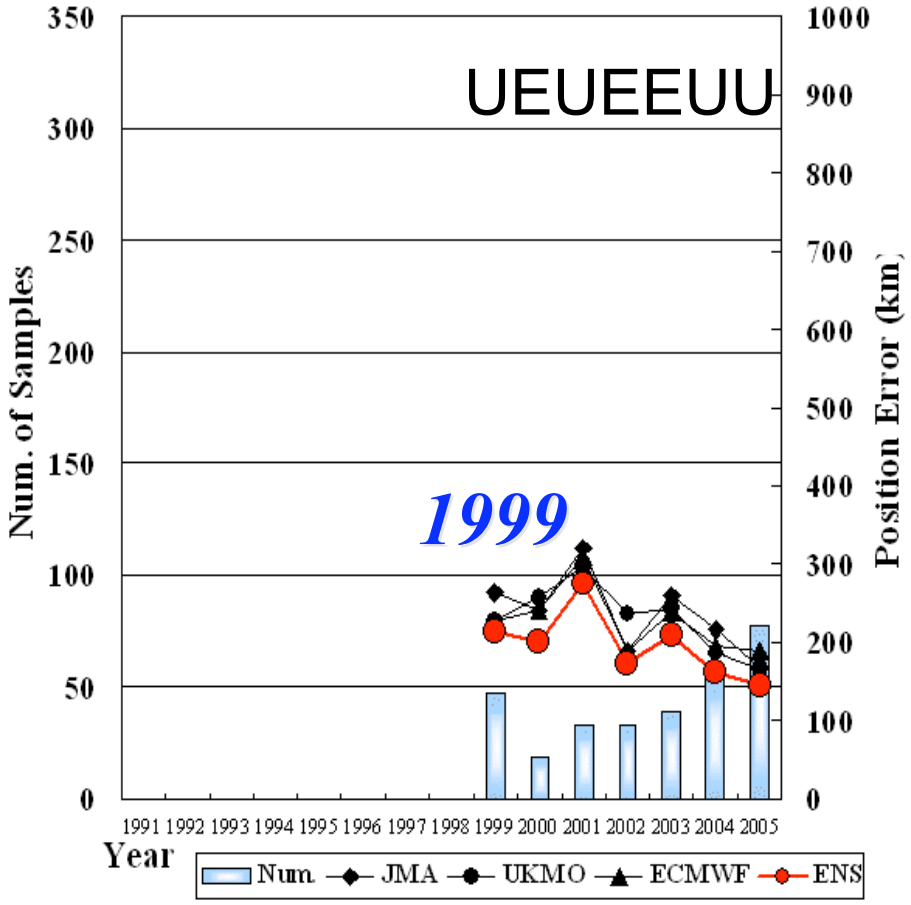
4day Forecast



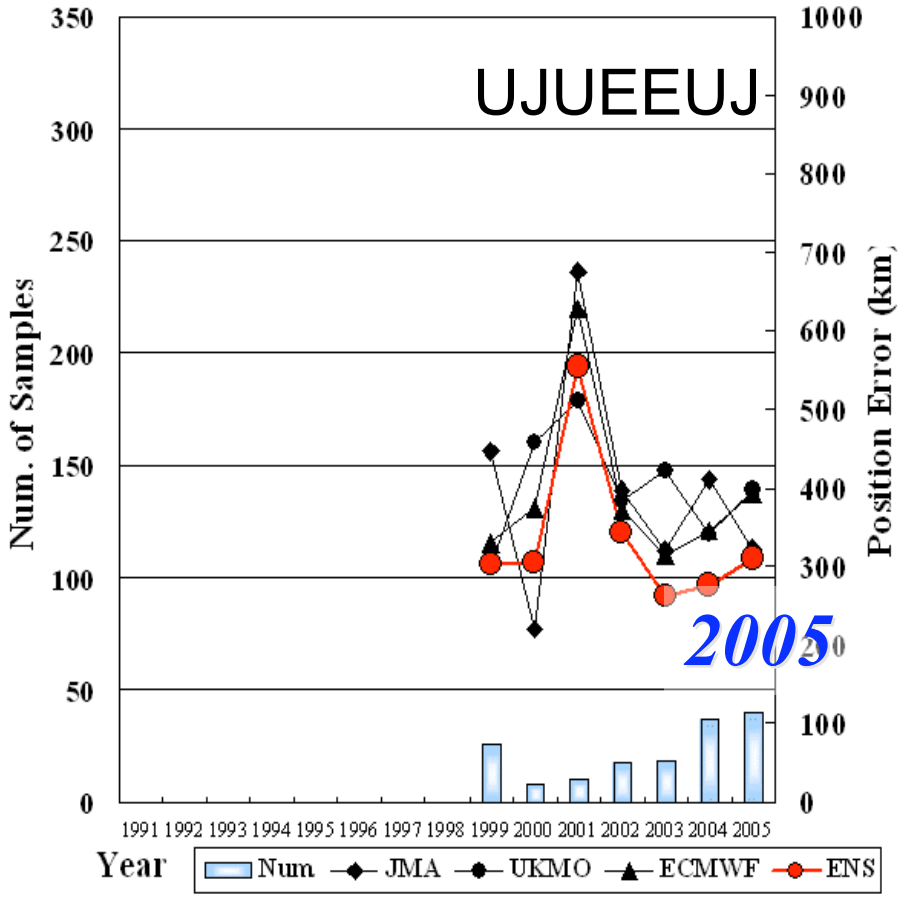
Multi-Center Ensemble (JMA, ECMWF, UKMO)

- North Atlantic area -

2day Forecast



4day Forecast

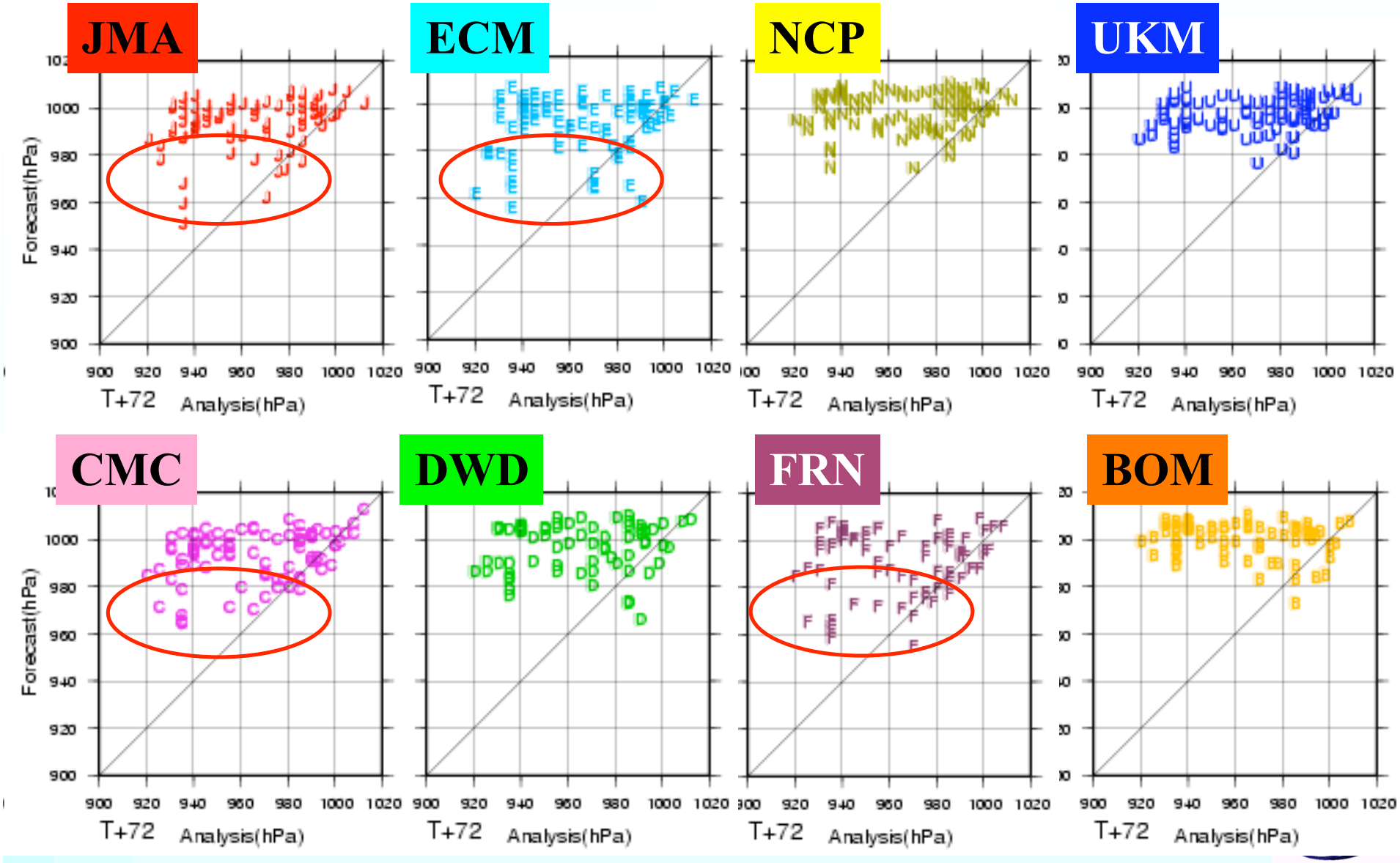


2.2 Systematic Error of Intensity

TC Intensity Verification

- western North Pacific area -

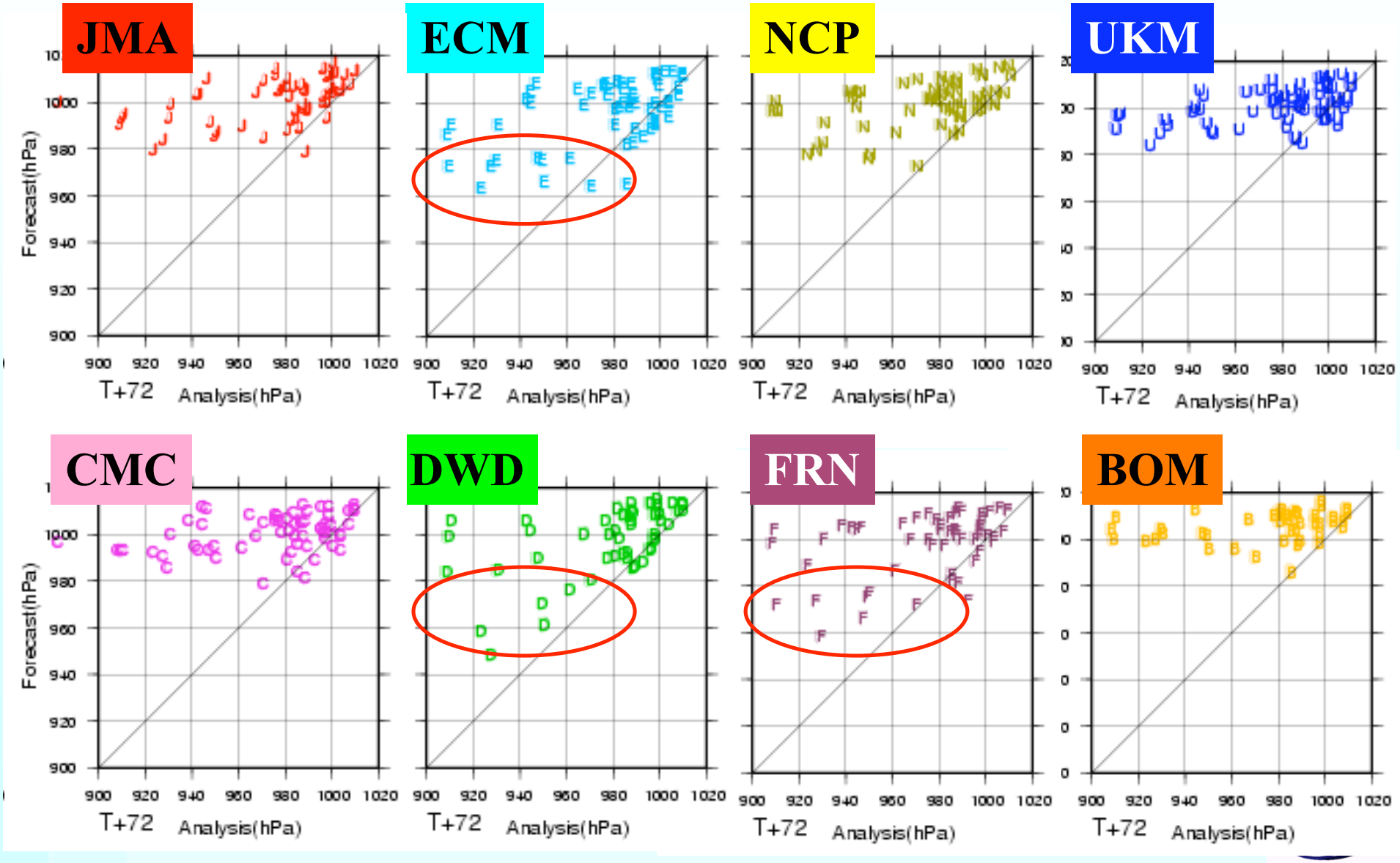
T+72



TC Intensity Verification

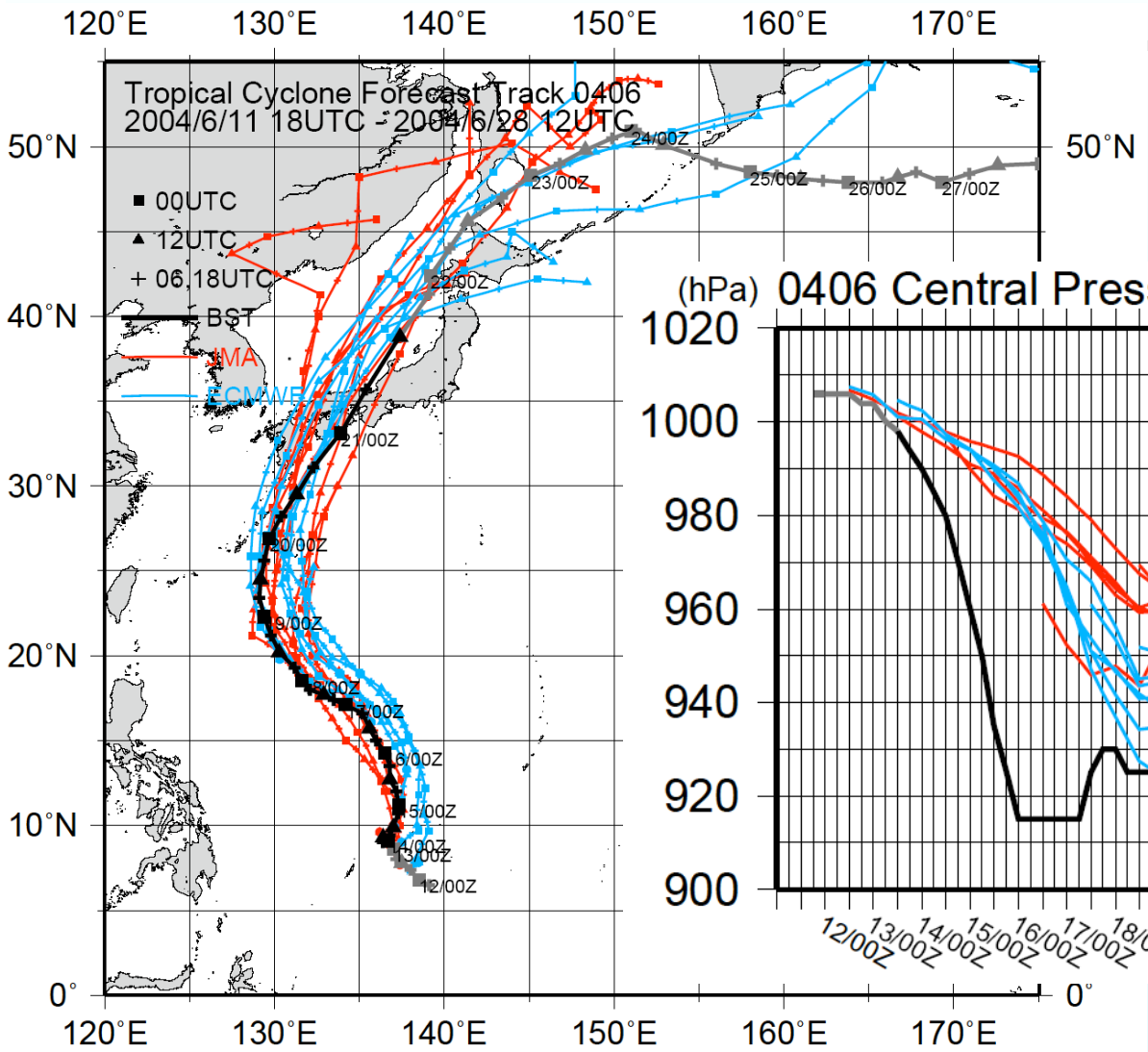
- North Atlantic area -

T+72



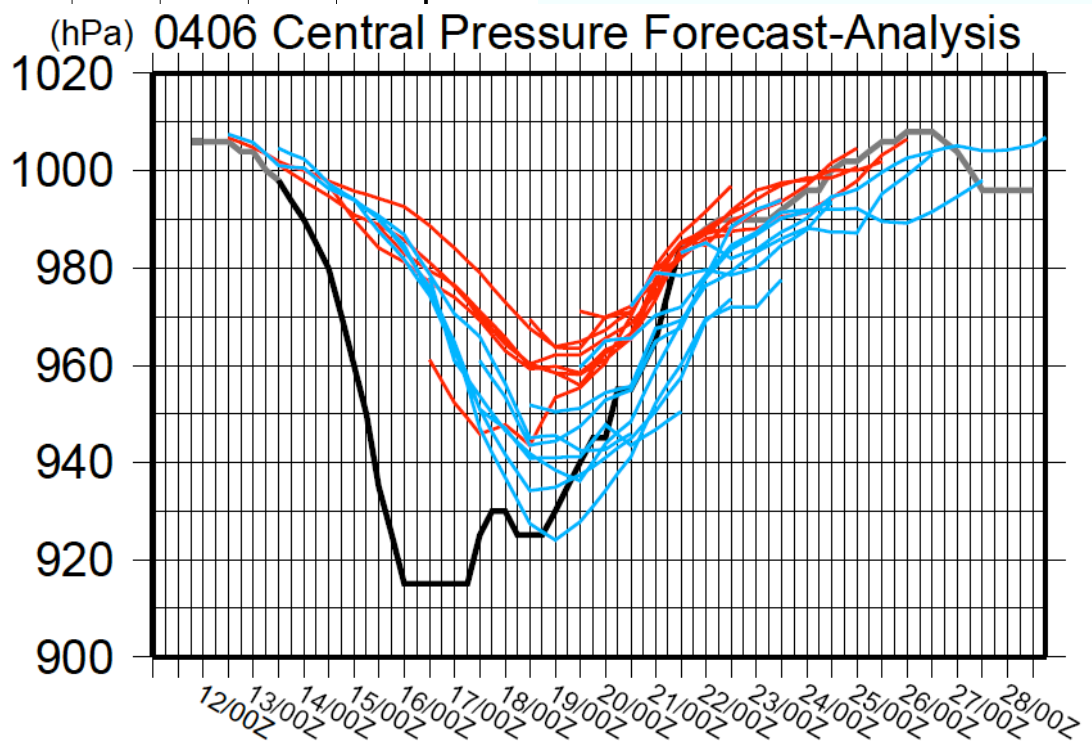
A Case Study for Typhoon DIANMU(T0406)

- western North Pacific area -



:JMA

:ECMWF



3. What Contributes the Improvement of TC Forecasts?

- New dynamics and parameterizations

- Data assimilation techniques (e.g. 3D-Var, 4D-Var, Variational QC, Variational Bias Correction)

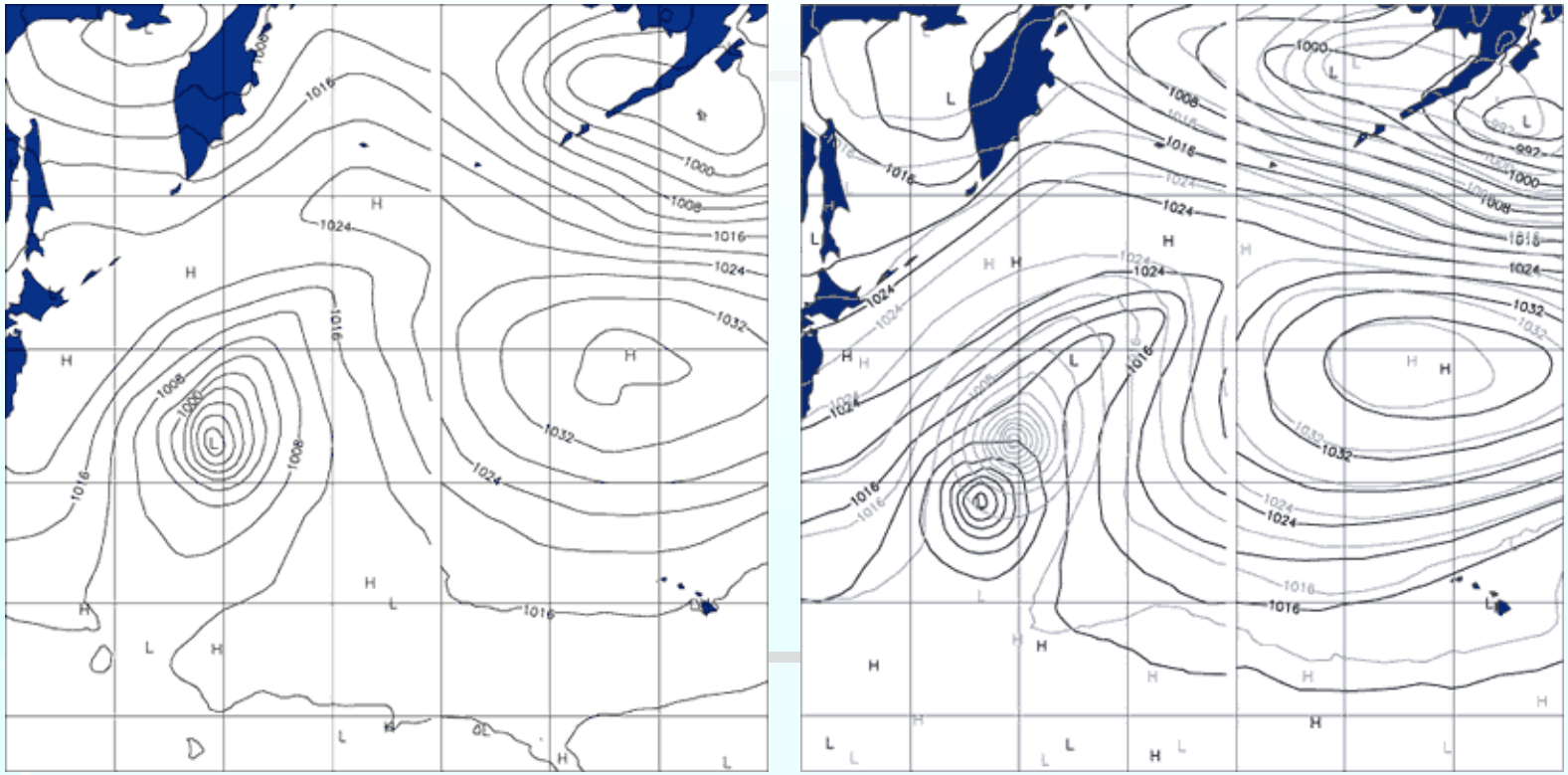
- New Observations (e.g. Dropsonde, ATOVS, QuikSCAT, MWR)

Development to improve TC Track
- UKMO -

- Higher-resolution **satellite winds**
- **Higher-resolution** global **model** (1998)
- **Initialization scheme** developments (1998) - Intensity
- **3D-Var**/**ATOVS** (1999)
- **New dynamics** (2002) - Intensity and Track
- **Satellite Radiance Data** (2004) - Track >10%
- **4D-Var** (2004) - Track >3%
- HadGEM **Physics** (2005) - Track >1.5%

After UKMO web site

Impact of the New UM



Forecasts of typhoon Podul from 27 October 2001. Operational analysis (top panel) and 96-hour forecasts (bottom panel). The New Dynamics forecast is shown overlaid (light blue) and is better in terms of position and intensity. (NWP Gazette 2002)

Development to improve TC Track
- ECMWF -

Buizza, 2004

- Several changes have been brought to the **4D-Var data assimilation**: new formulation and tuning of the background (Jb) and observation (Jo) statistics (in October 1999 and June 2000); nonlinear balance (introduced in January 2003); move from a six to a 12-hour optimisation period (September 2000); new humidity analysis (October 2003);
- Many **new satellite observations** have been activated, among which are SeaWinds from **QuikSCAT** (January 2002), **SSMI winds** (October 1999), **AMSU** (since May 1999) and **AIRS** (October 2003) radiances. **Clear-sky radiances** from geostationary satellites have been actively assimilated since July 1999;
- **Dropsondes** (such as those released in or around TCs) have been activated in the data assimilation since July 1999; **higher-resolution winds** derived from geostationary satellite sequences have also been included in several steps during the period;
- **Model vertical and horizontal resolution** were increased in March and October 1999 and in November 2000;

Development to improve TC Track
- ECMWF -

Buizza, 2004

- Several important changes have been made to the **microphysics and convection schemes** (October 1999, January 2003 and October 2004);
- The **oceanic wave model was fully (two-way) coupled to the atmospheric model** in June 1998, with important consequences to the representation of momentum, heat and humidity fluxes near the sea surface;

Assimilation of rain-affected microwave radiances and improvement of humidity analysis

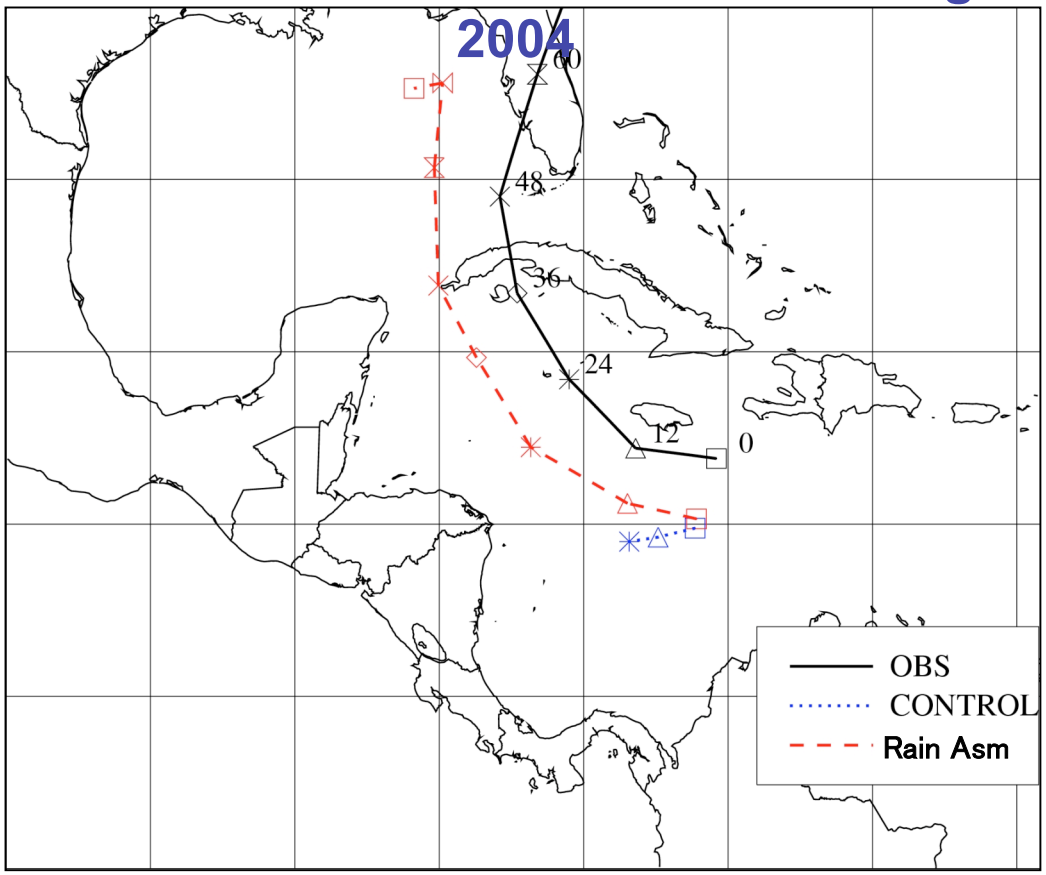
Miller, 2005

Comparison of cycle 29r2 e-suite and operations with independent TCWV retrievals from Jason microwave radiometer (may 2005)

	e-suite	ops
Global	1.74	1.90
N. Hemisphere	1.63	1.71
Tropics	2.12	2.43
S. Hemisphere	1.53	1.62
N. Atlantic	1.63	1.69
N. Pacific	1.57	1.69

stdev (kg/m^2)

Hurricane Charley
Track forecasts from 12 UTC 11 Aug 2004



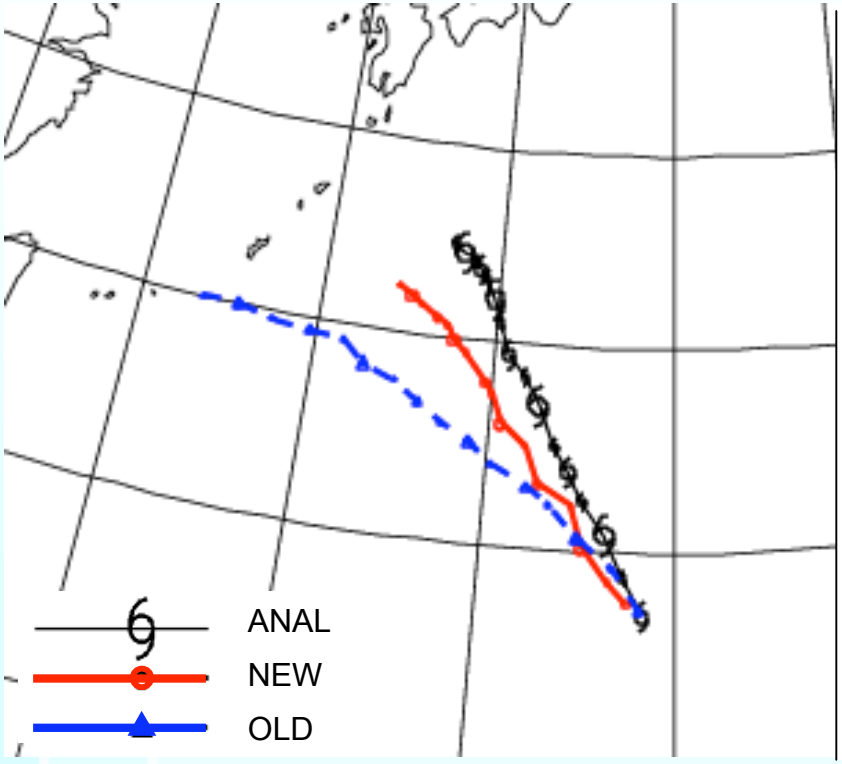
ECMWF

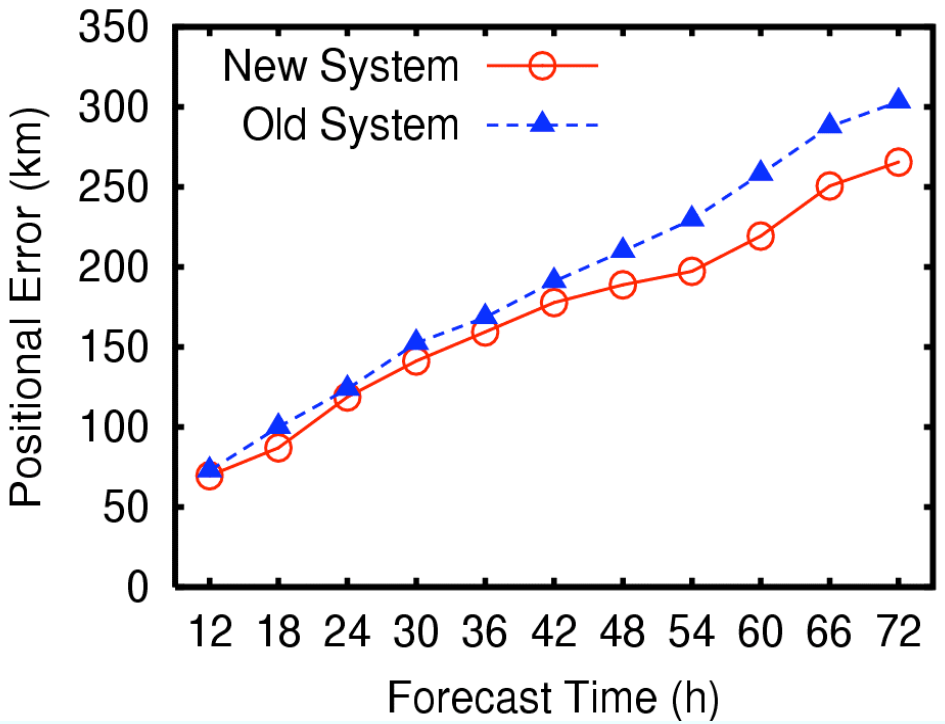
Development to improve TC Track

- JMA -

Impact of the Global 4D-Var (2005.2)

Impact Study with JMA GSM T213(outer)/T63(inner)





Predicted tracks of typhoon T0416 (CHABA). Initial time is 12UTC 24 August 2004. ANL: analysis, NEW: new system, OLD: old system. Plotted every 6 hours.

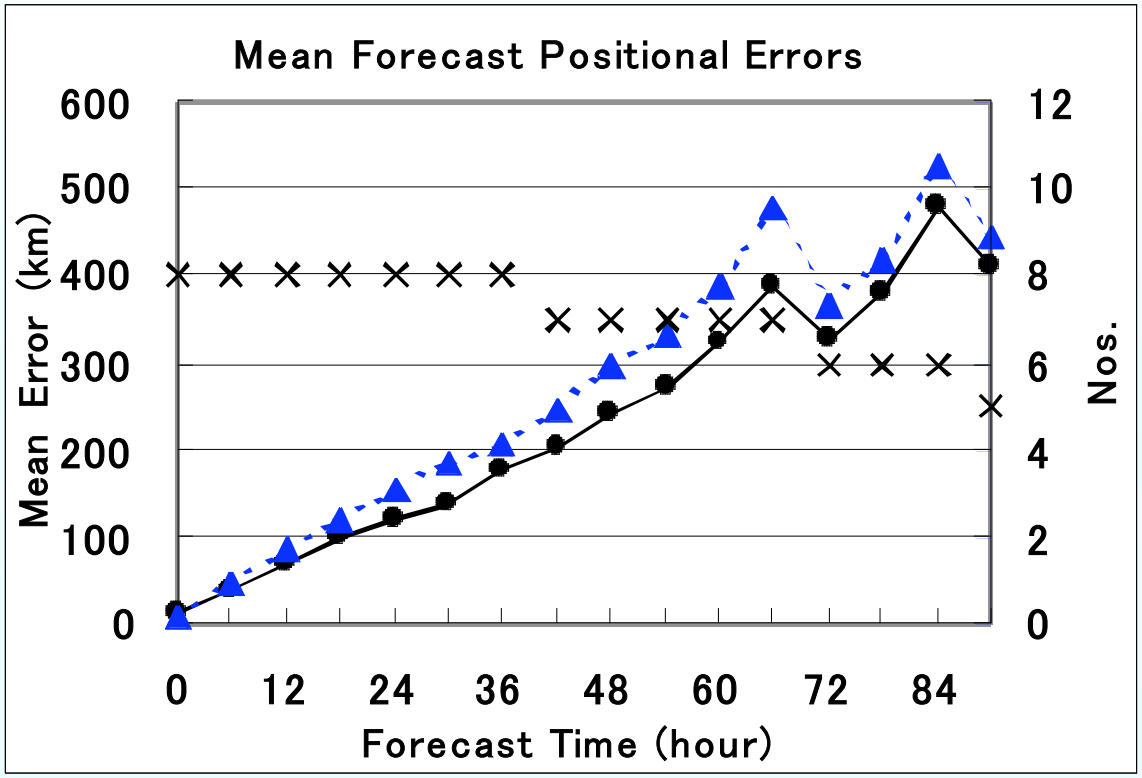
Mean positional error for eight typhoons in August 2004 by new system (circle) and by old system (triangle). The number of samples is 39 at 12-hour forecasts.

Kadowaki, 2005

Impact of dropsonde on typhoon track forecasts with GSM

- DOTSTAR (Dropsonde Observations for Typhoon Surveillance near the Taiwan Region) Project -

The experiments were made for typhoons of Dujuan (T0313), Melor (T0319), Nida (T0402), Conson (T0404) and Mindulle (T0407) with and without dropsondes data.



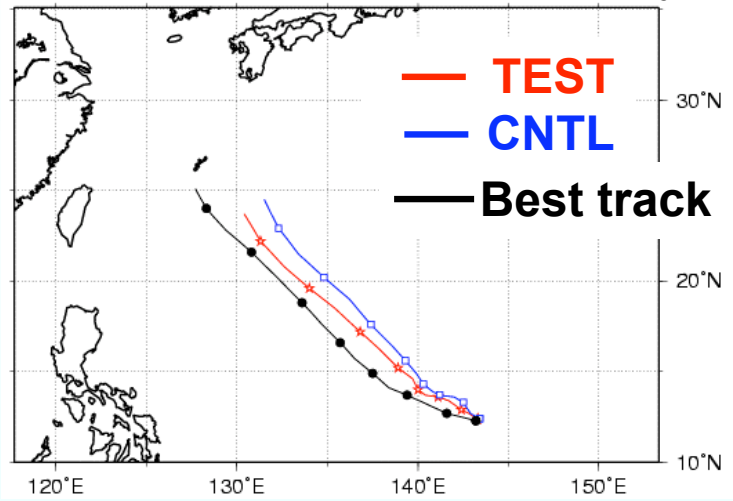
Black circles: mean error of typhoon track forecasts with dropsondes
Blue triangles: without dropsondes
Cross marks: number of samples.

Iriguchi, 2005

Impact of QuikSCAT on typhoon track forecasts with GSM

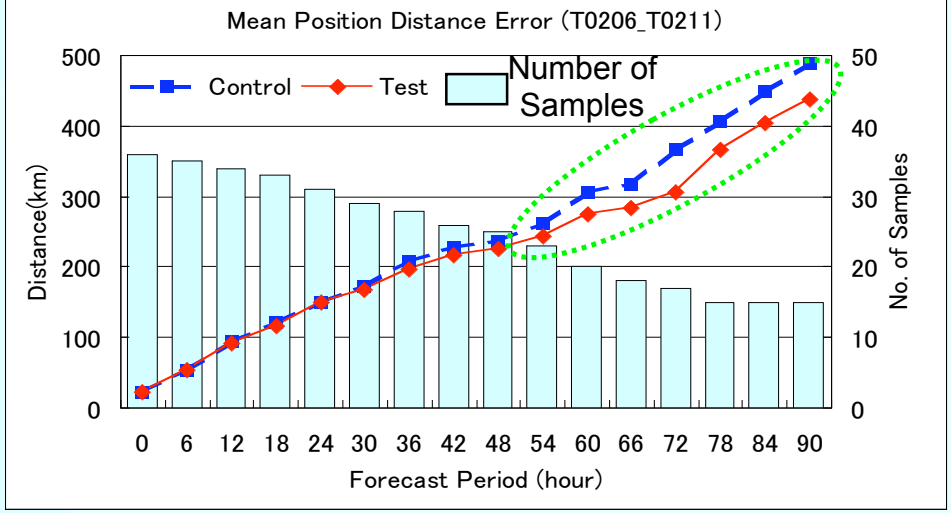
(2003.5)

Typhoon track forecasts for typhoon T0207 (HALONG). Initial: 12UTC 10 July 2002.



- The position error of forecasted typhoon track with QuikSCAT sea surface wind (TEST) was obviously improved.

Statistical verification of typhoon forecasts

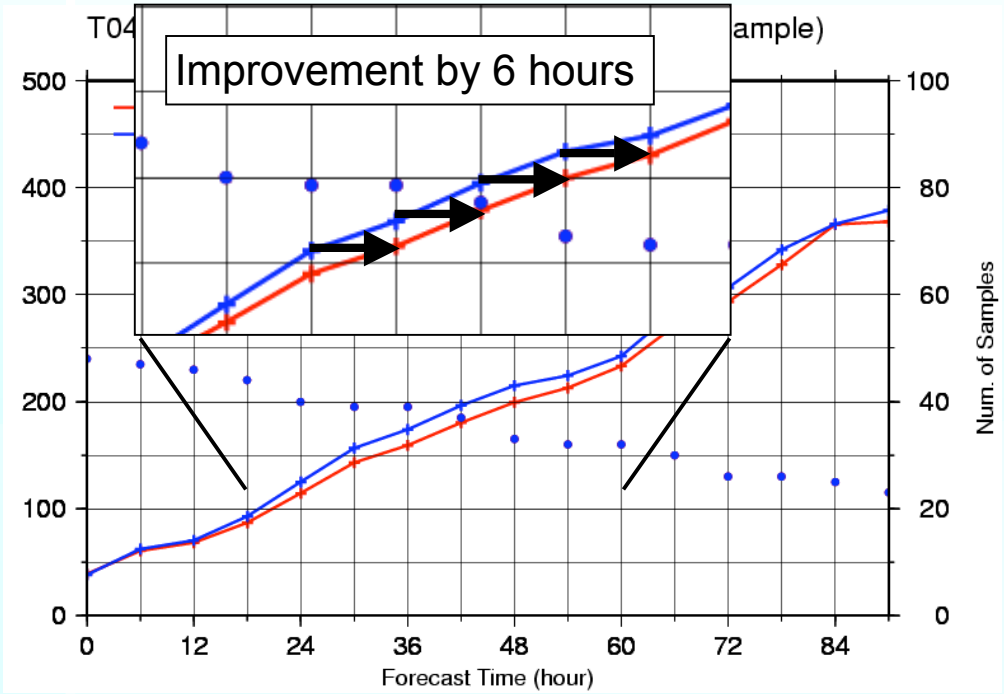


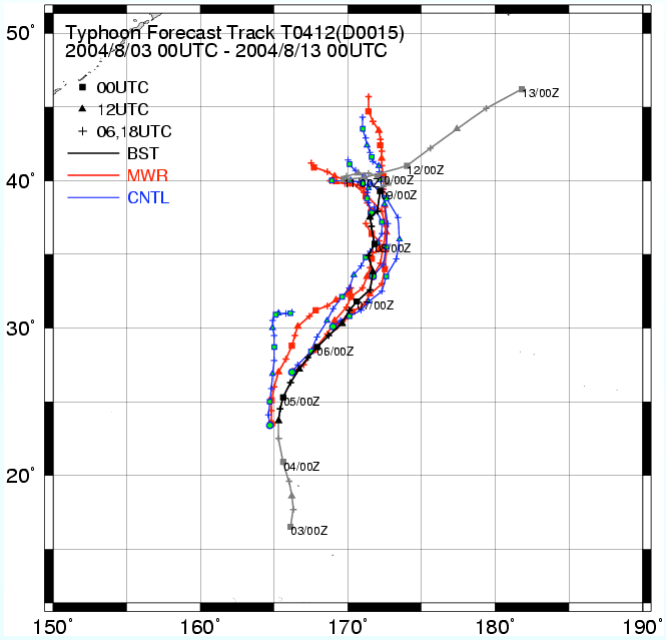
- The mean position error of typhoon track forecasts in TEST and CNTL in 36 case for 6 typhoons during Jul. 2002.
  - The position errors in TEST were significantly reduced after 60 hour forecast.

Oohashi, 2004

Impact of Microwave Imagers

- Direct assimilation of SSM/I, TMI, and AMSR-E radiance data (2006.5)
- Introduction of a variational bias correction for microwave sounder and imager data (2006.5)





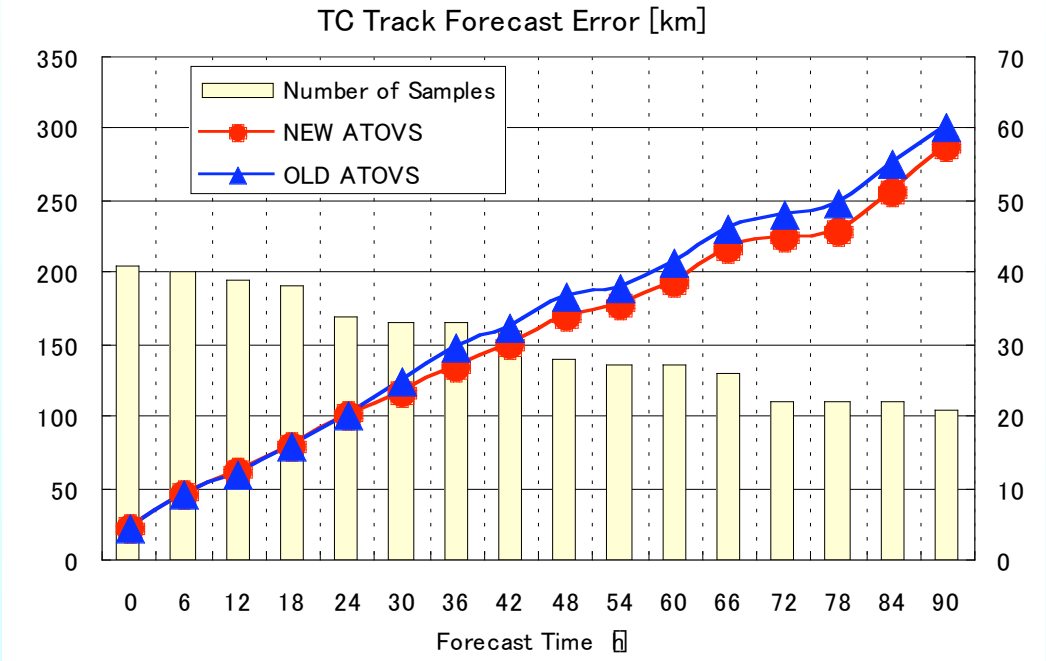
Improvement of typhoon track forecasts in August 2004

Red: with MWRs, Blue: without MWRs

Sato, 2007

Impact of Improved Use of ATOVS

Implementation of an improvement of assimilation system for ATOVS (2006.8)
- QC and Bias correction, revision of observation error -



The position error of forecasted typhoon track in New ATOVS was obviously reduced after 30 hour forecast.

The mean position error of typhoon track forecasts in TEST and CNTL against best tracks during Jul. – Sep. 2004. Bars denote number of samples for the verification.

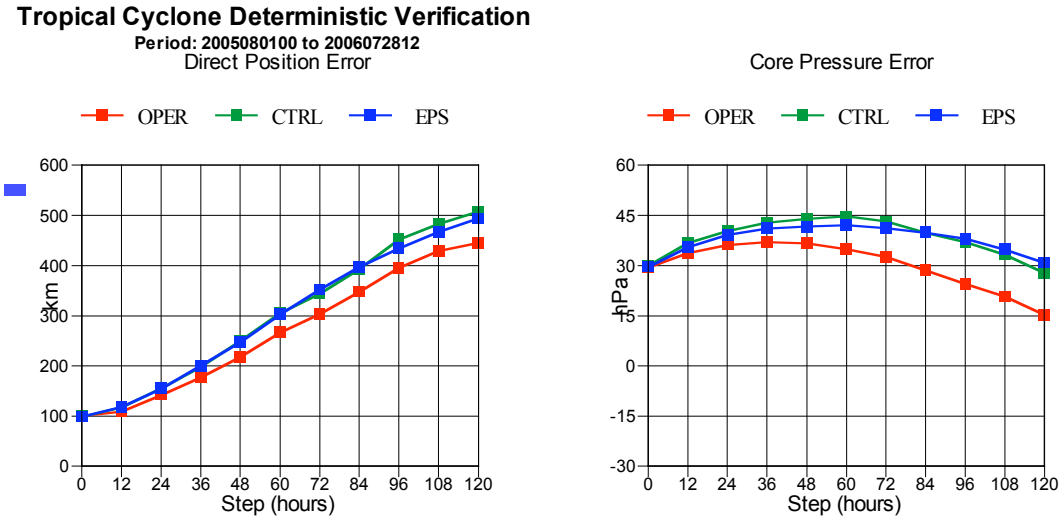
Okamoto, 2007

4. Toward the Reduction of Systematic Error - Higher Resolution Model -

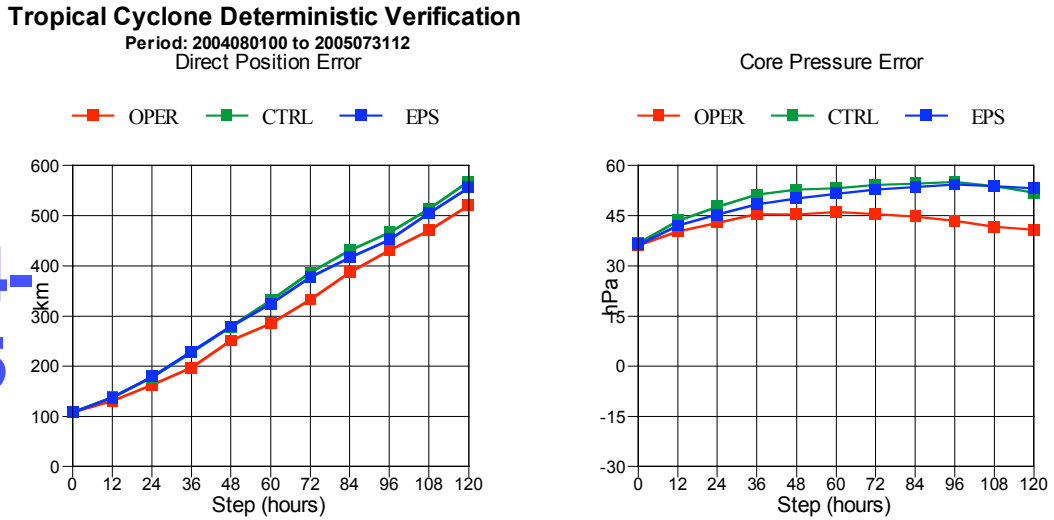
ECMWF, CMC, JMA Activities

Tropical cyclone verification

2005-2006



2004-2005



T799 (25km) model was implemented in Feb. 2006

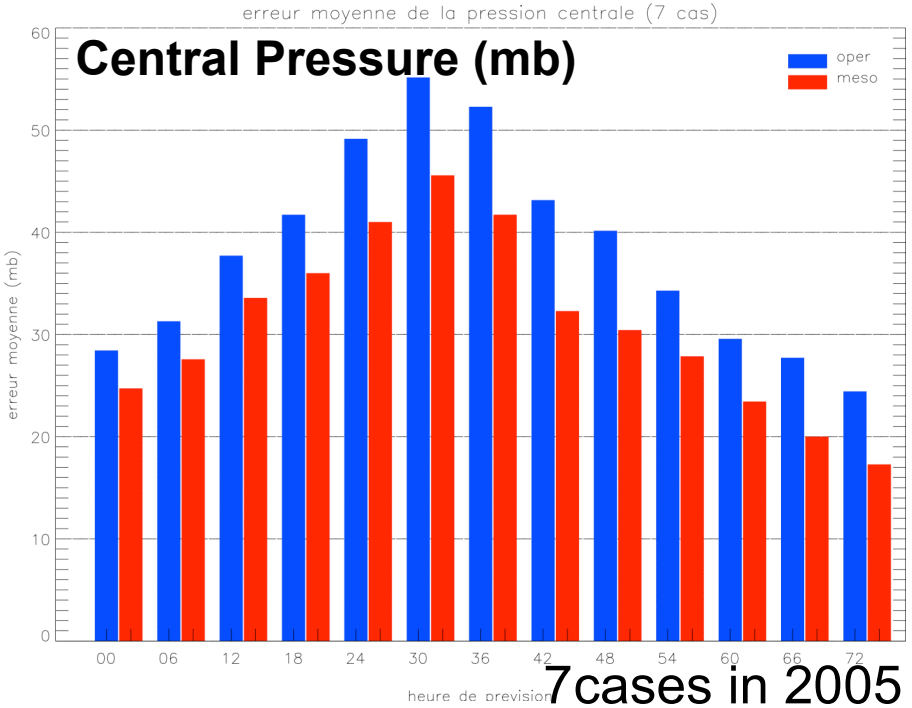
Miller, 2006

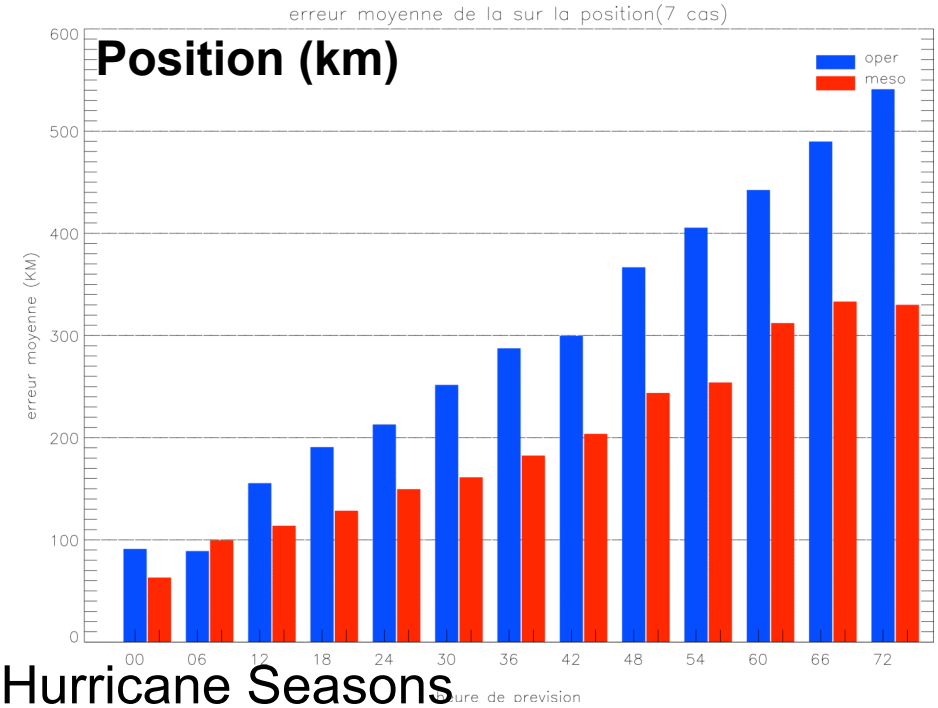
ECMWF

Global-Meso Model (CMC) (Oct. 2006 -)

Leads: S. Bélair, S. Laroche and M. Roch

- Increased horizontal and vertical resolution
  - 800 × 600 × 58L (~33 km) vs 400 × 200 × 28L (~100 km)
- Representation of clouds
  - Shallow convection with Kuo Transient
  - Deep convection with Kain-Fritsch
  - Modified Sundqvist scheme for grid-scale condensation
- Bougeault-Lacarrère for turbulent mixing length





7cases in 2005 Hurricane Seasons

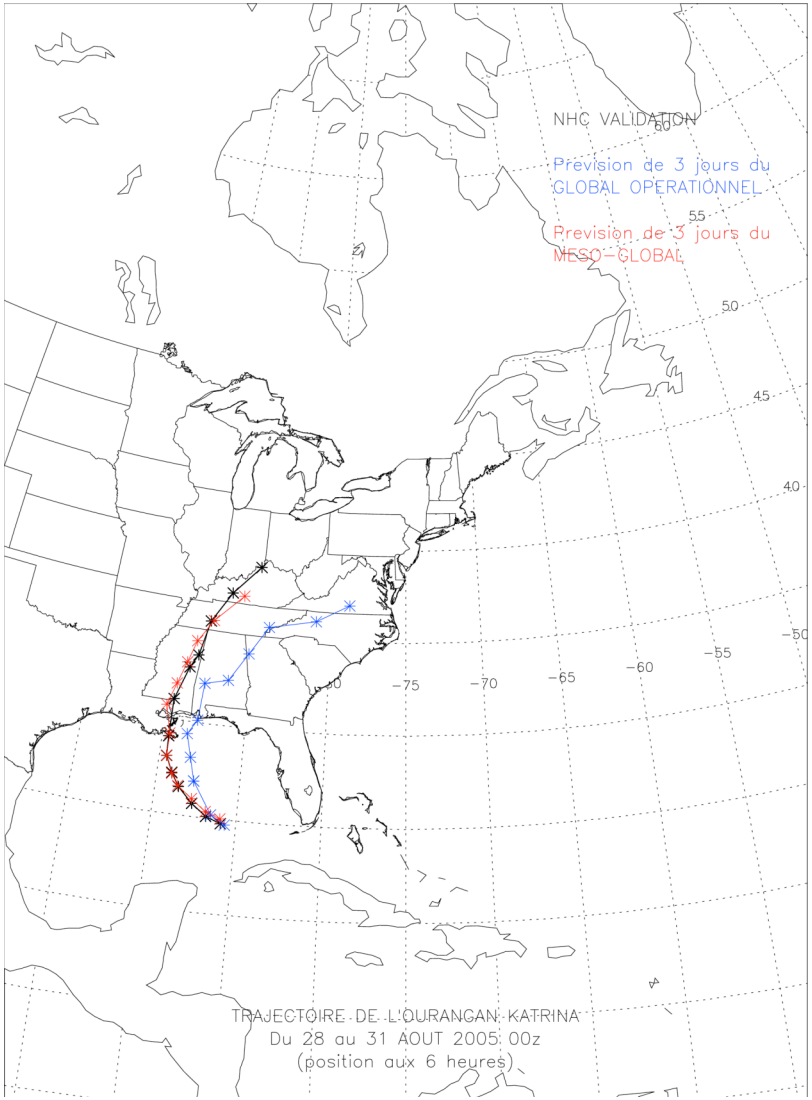
13 August 2005 – 18 October 2005

After Brunet, 2006

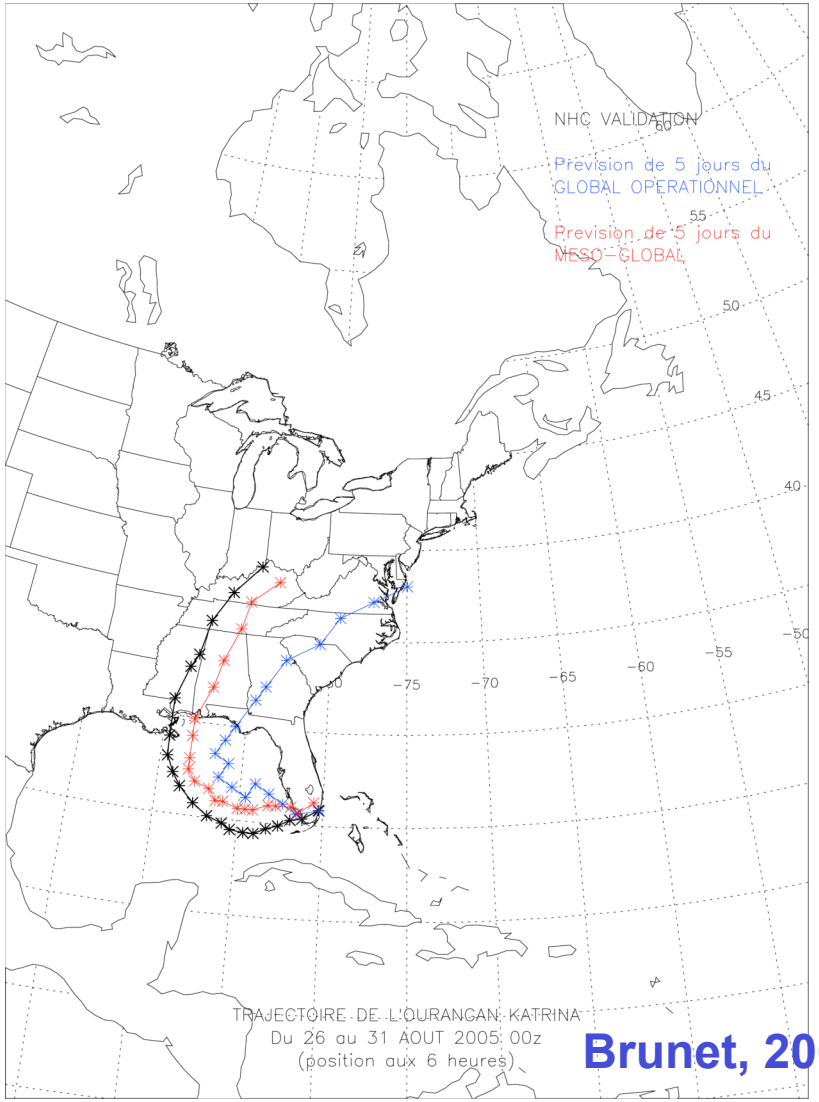
Katrina

Intercomparison

72 hours



120 hours

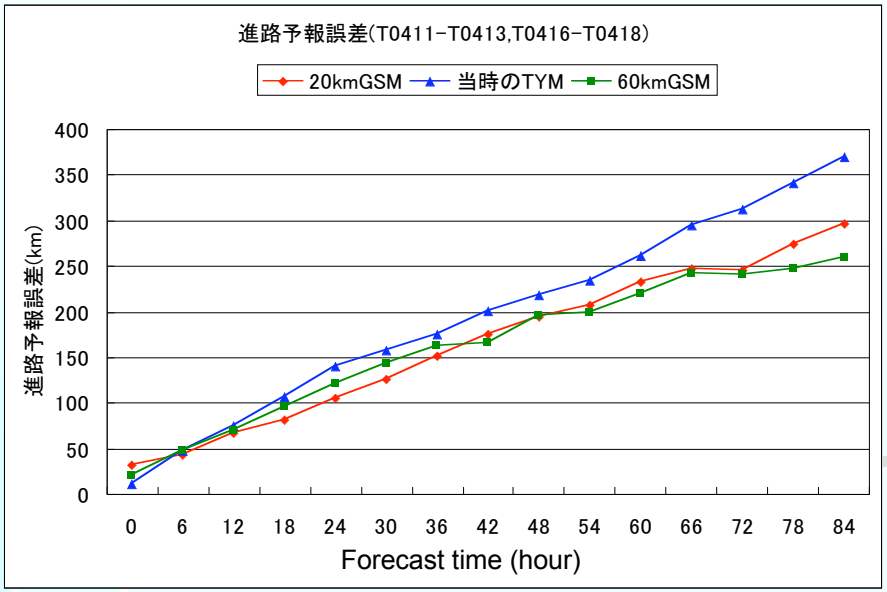


Brunet, 2006

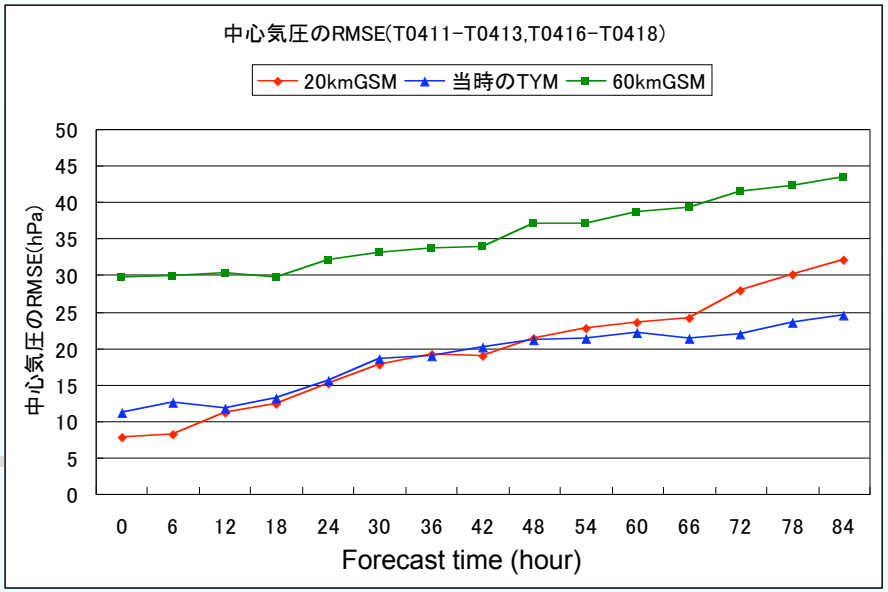
TL959L60 Global Model (20km-GSM)
(4Q 2007 or later)

Parallel Run Test for August 2004

RMSE of typhoon central position



RMSE of typhoon central pressure

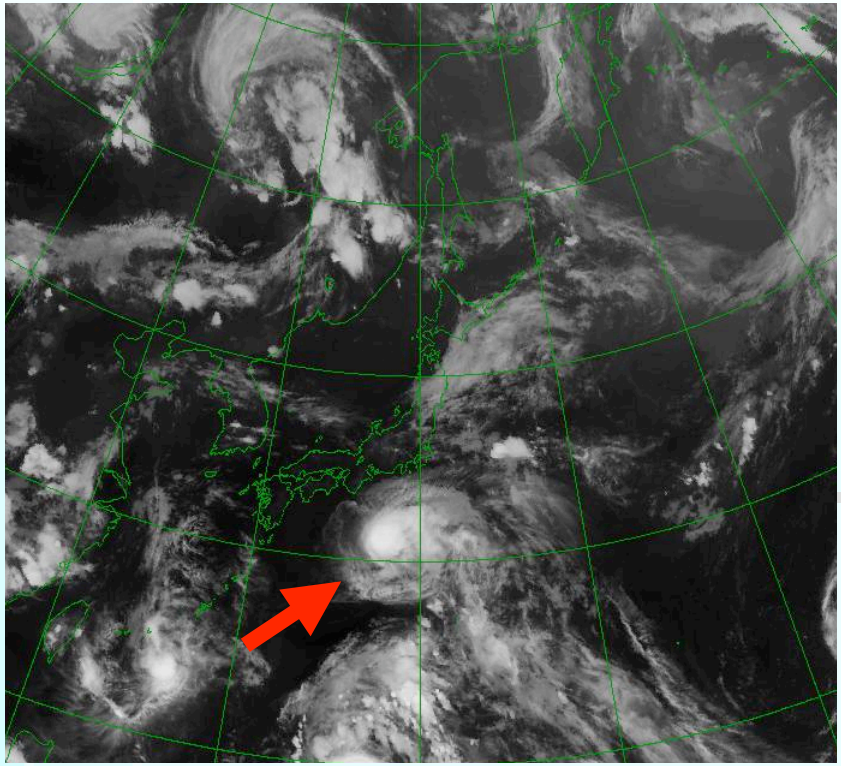


RMSE of typhoon intensity forecasts is much reduced by increasing horizontal resolution from 60 km to 20 km, but it may not be easy to beat the **Typhoon Model** (TYM, 24 km resolution), which has been well tuned for typhoon forecasts only.

TL959L60 Global Model (20km-GSM)

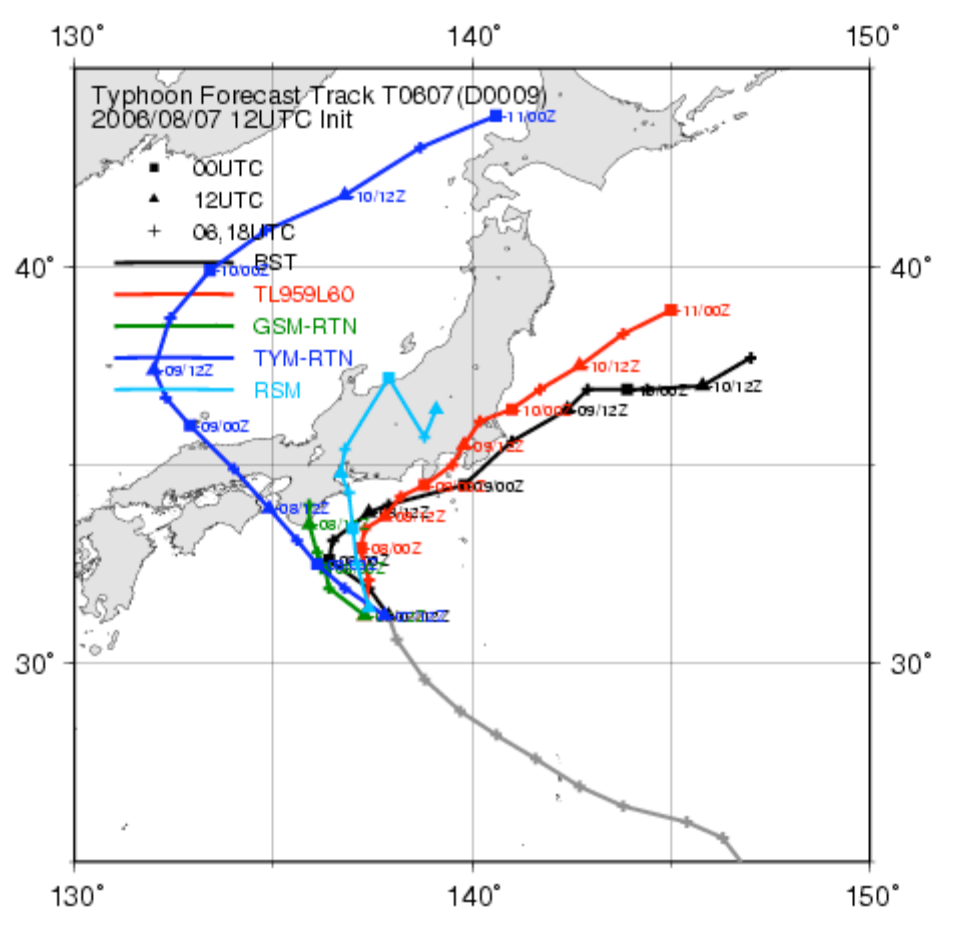
Forecast Experiment for T0607

IR image from MTSAT-1R (12 UTC 7 August 2006)



20km-GSM is superior to other JMA models for predicting small scale typhoons such as T0607, of which radius of 30 knot wind was about 40km.

Comparison of typhoon track forecasts (Initial time: 12 UTC 7 August 2006)



5. Summary and Concluding Remarks

- WGNE TC comparison project has monitored operational typhoon forecasts over 15years. Position error of TC forecast is a good metrics to measure the total performance of NWP system (model, assimilation etc.).
- Remarkable improvement has been achieved in particular for last several years.
- The improvement of TC forecast can be attributed to the development of model and data assimilation and the implementation of new data.
- This trend will be continued due to promising new model (e.g. higher res. model with sophisticated physics) and new data assimilation (e.g. 4D-Var, EnKF) and new data (e.g. GPS occultation, Dopplar lidar etc.)
- Some systematic bias such as slow bias after recurvature has not resolved yet; further investigations are required.
- Systematic track bias of single model can be relaxed partly by use of Multi-Center Ensemble from the view of application.
- Systematic bias of intensity will be much reduced by higher-resolution models, on the other hand, the reduction of track bias by HRM is unobvious.