Ensemble Tropical Cyclone Activity Prediction using TIGGE data

JMA/WMO Workshop on
Effective Tropical Cyclone Warning in Southeast Asia
Tokyo, Japan

12 March 2014 (Wed)

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4: Bureau of Meteorology in Australia
5: World Meteorological Organization

Outline of the talk

1. Introduction of TIGGE
   What is TIGGE?
   What is the benefit of using TIGGE?

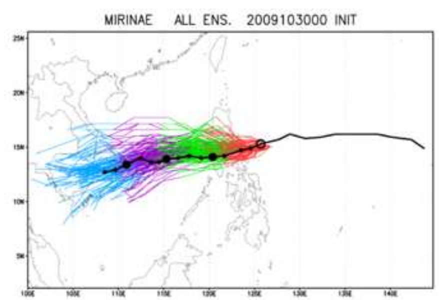
2. Ensemble tropical cyclone activity prediction
   Motivation,
   Verification Method,
   Results,
   Future Plan

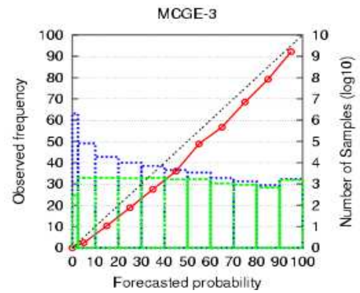
3. Topic: Multi-center ensemble predictions for Hurricane Sandy, Cyclones Phailin and Nargis, and Typhoon Haiyan

4. Summary

What is TIGGE?

Past		Future
Research Phase		Operational Phase
TIGGE (started 2006)	Cyclone XML (started 2008)	





Goal: Enhanced use of ensemble prediction for operational purposes

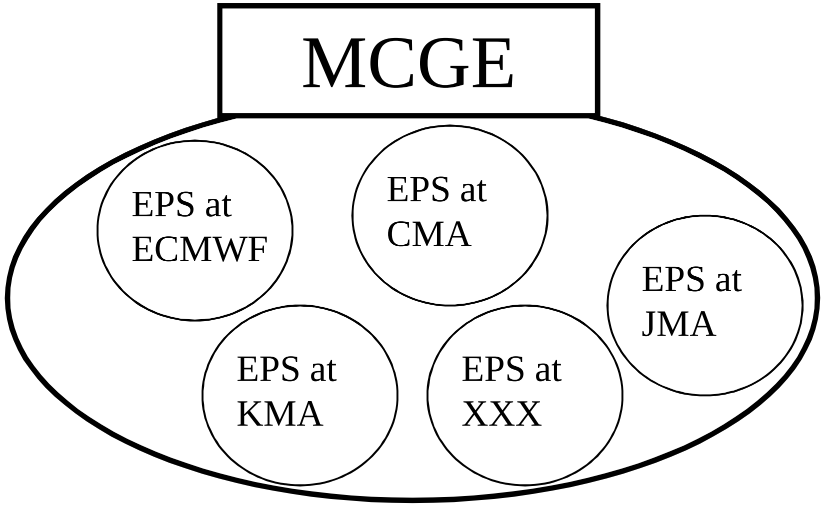
Present

Various projects to demonstrate the value of ensemble prediction have been conducted.

- North Western Pacific Tropical Cyclone (TC) Ensemble Forecast Project (NWP-TCEFP)
- Severe Weather Forecasting Demonstration Project (SWFDP)

What is the benefit of using TIGGE?

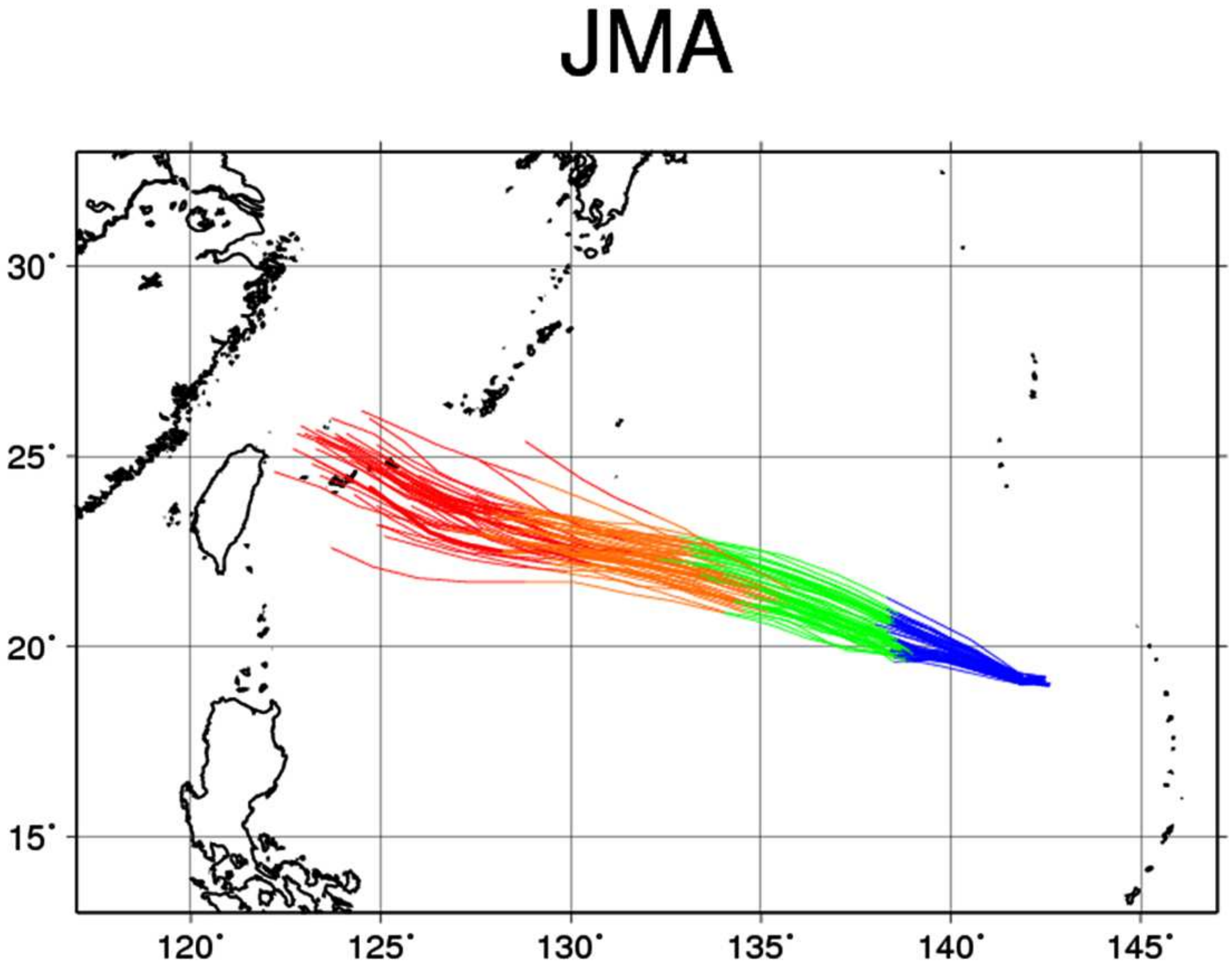
Past	
Research Phase	
TIGGE (started 2006)	Cyclone XML (started 2008)



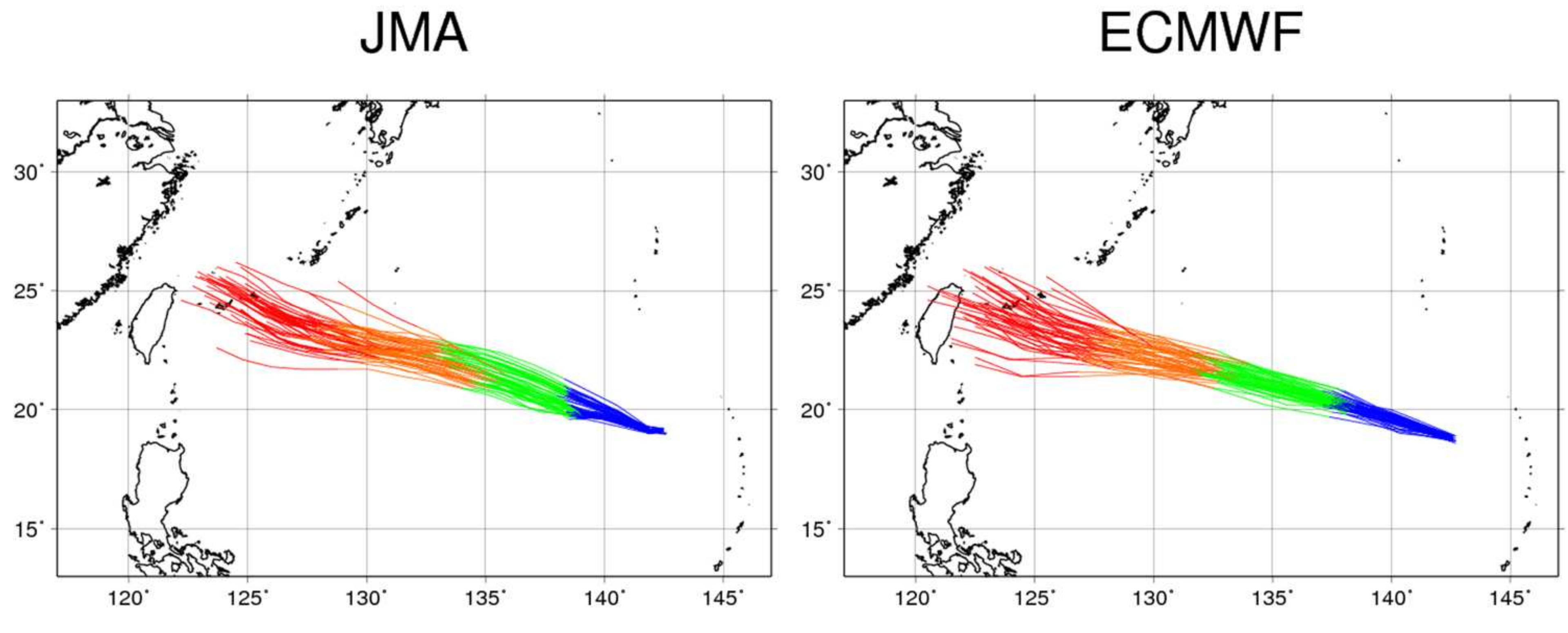
MCGE is an ensemble of ensembles of major NWP centers.

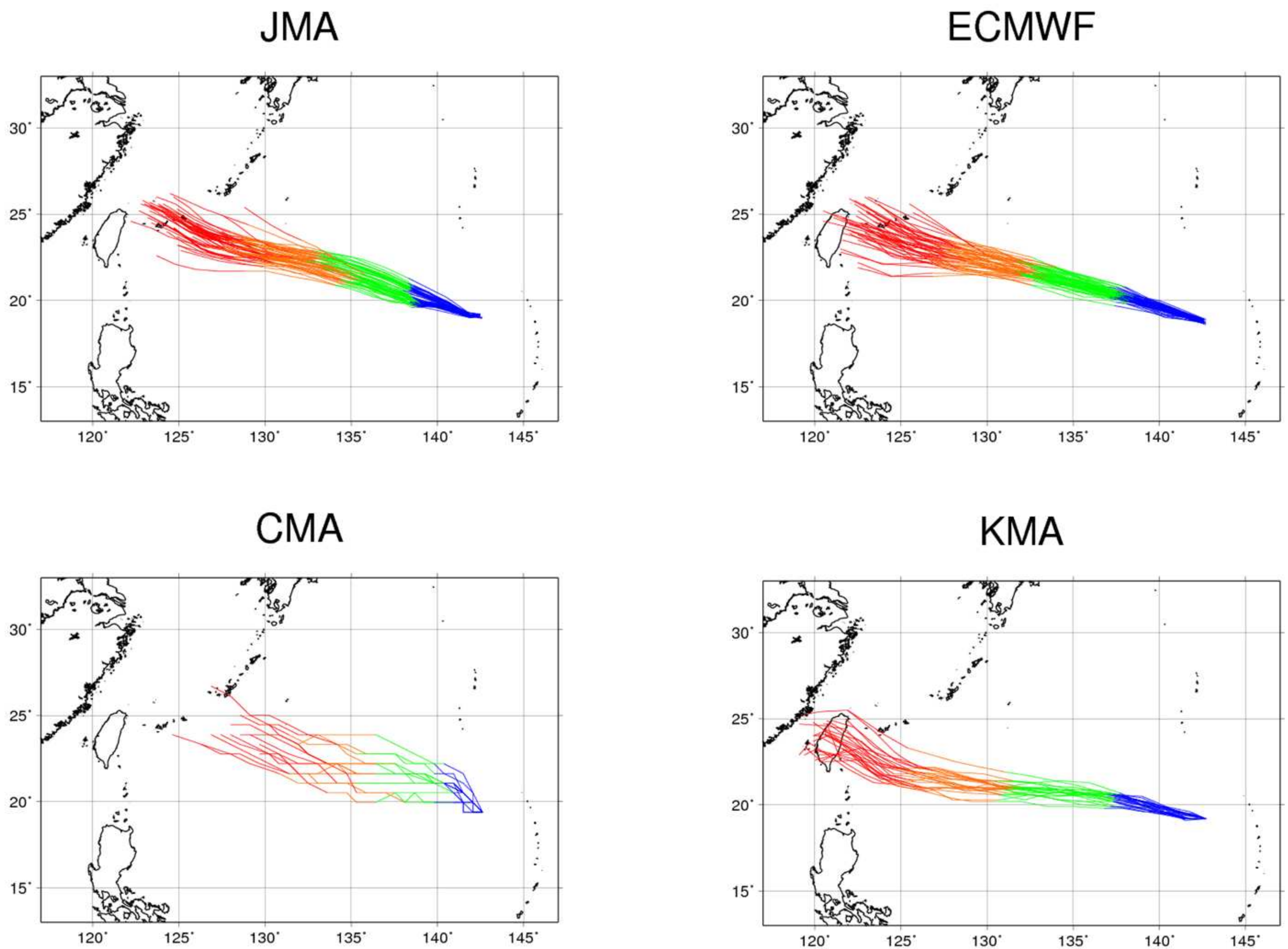
TIGGE makes it possible to construct a new ensemble, which is Multi-Center Grand Ensemble (MCGE).

Track Prediction for Typhoon SOULIK (2013)



Blue portion of the tracks is the Day 1 forecast and the green, orange, and red portions are the Day 2, Day 3, and Day 4 forecasts.


JMA
ECMWF
30°
25°
20°
15°
120°
125°
130°
135°
140°
145°


JMA
ECMWF
CMA
KMA
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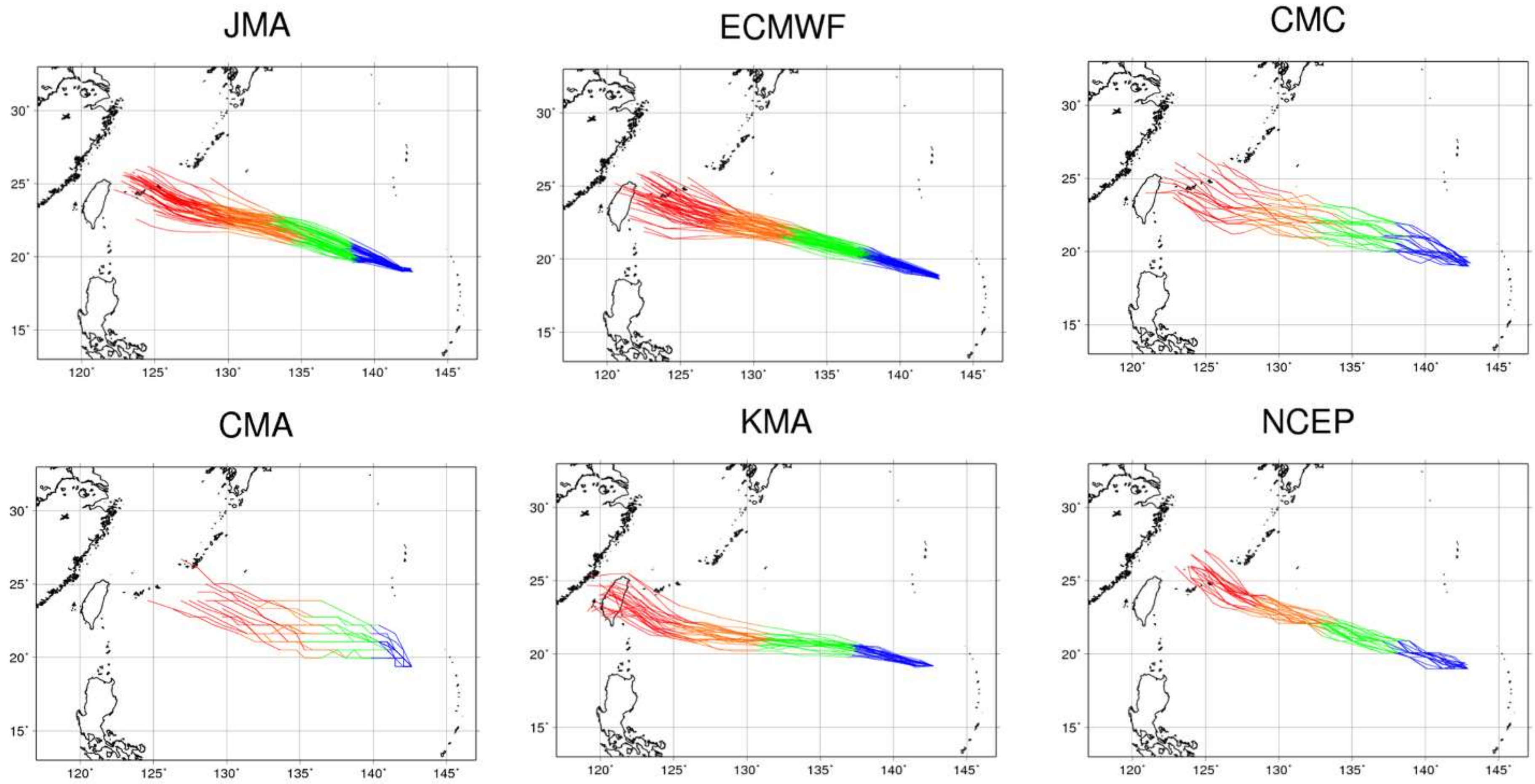
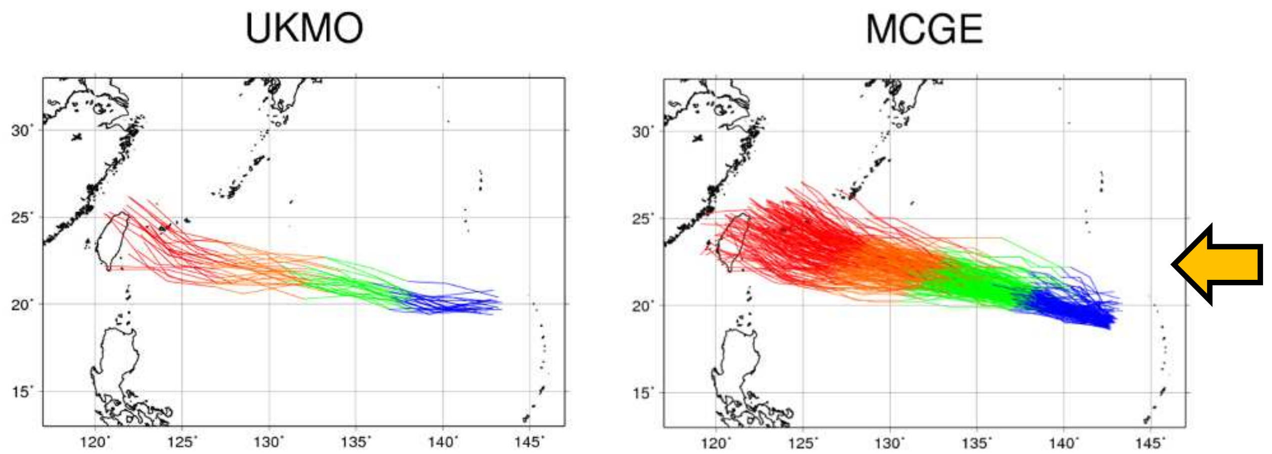
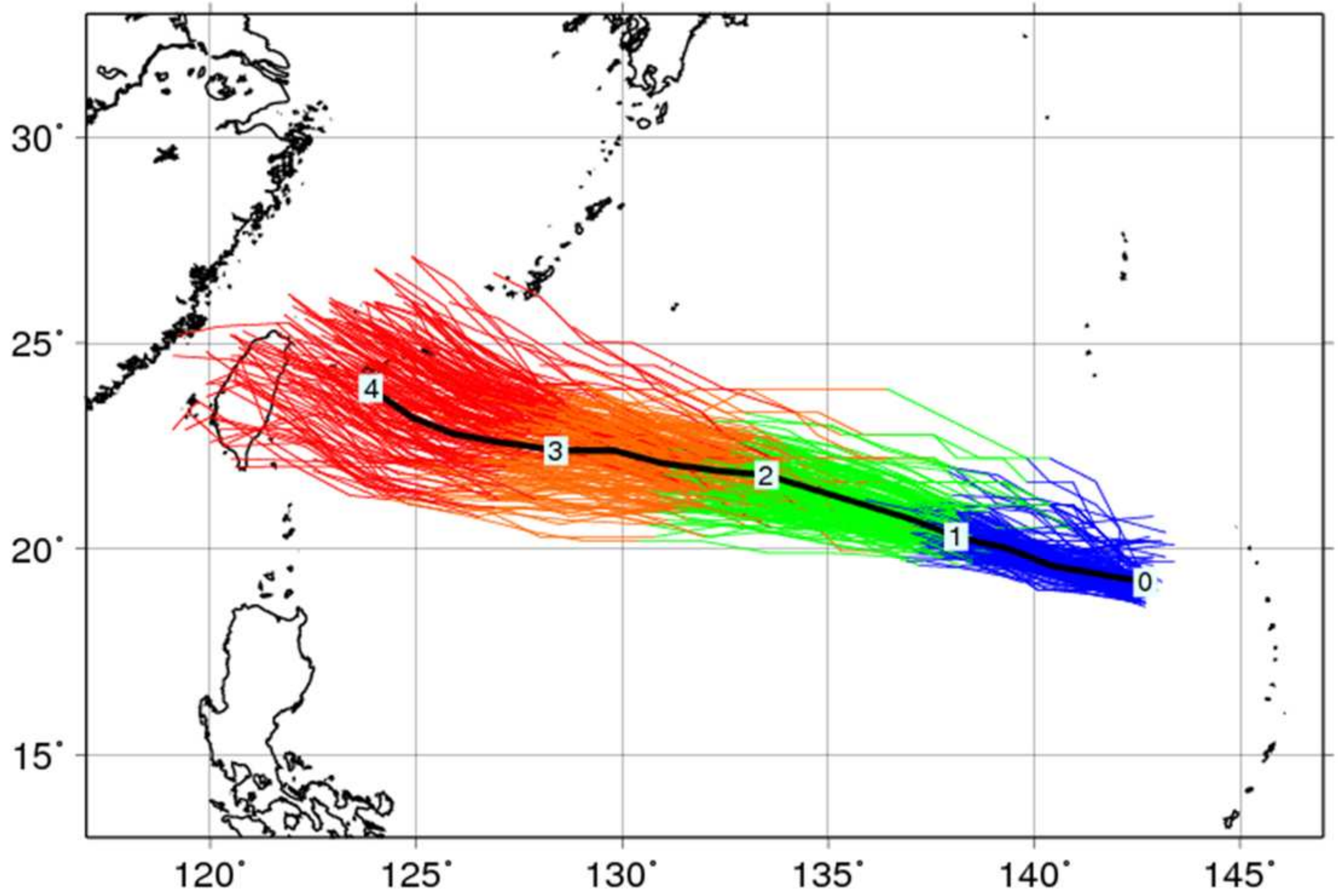




Ensemble Size =

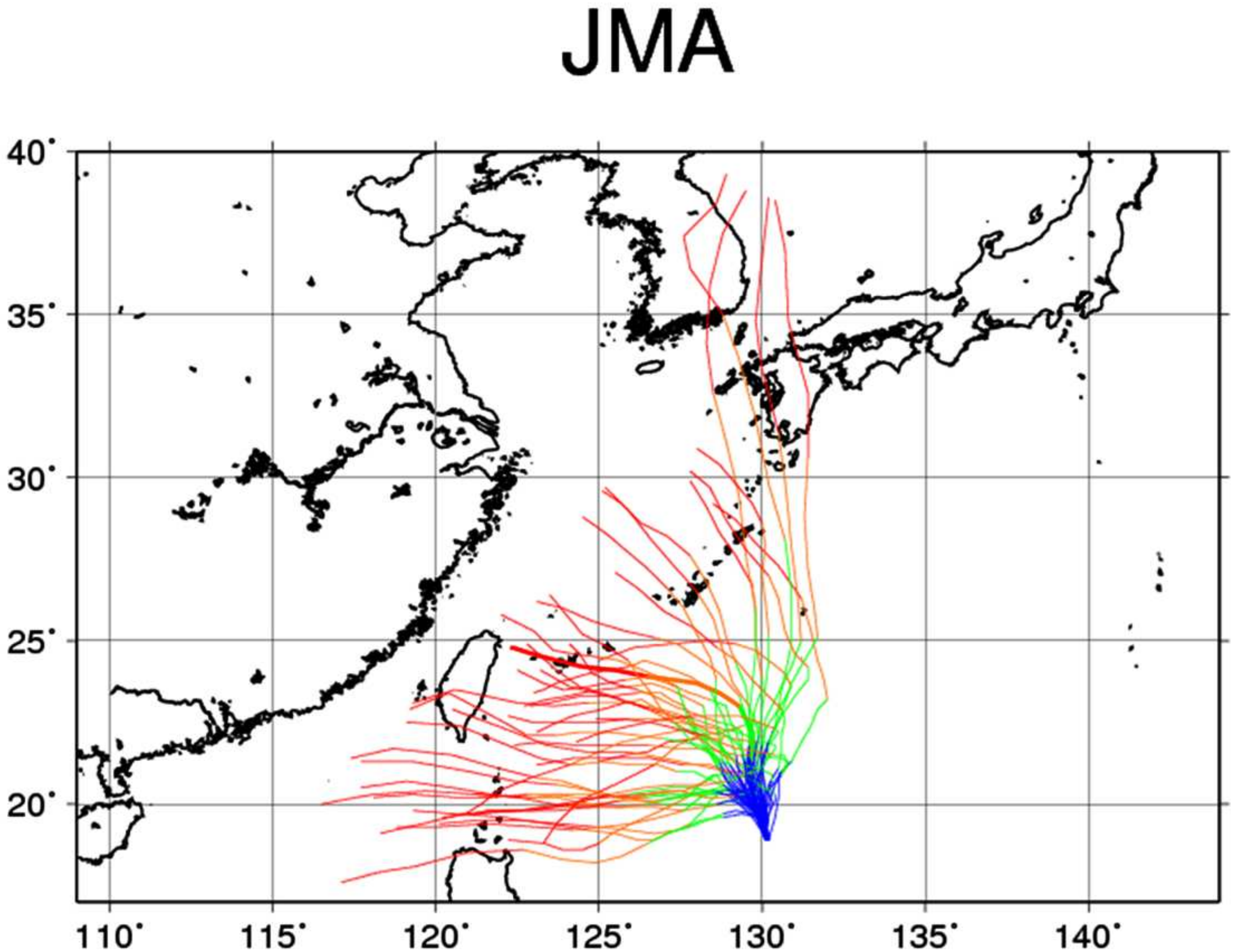
207

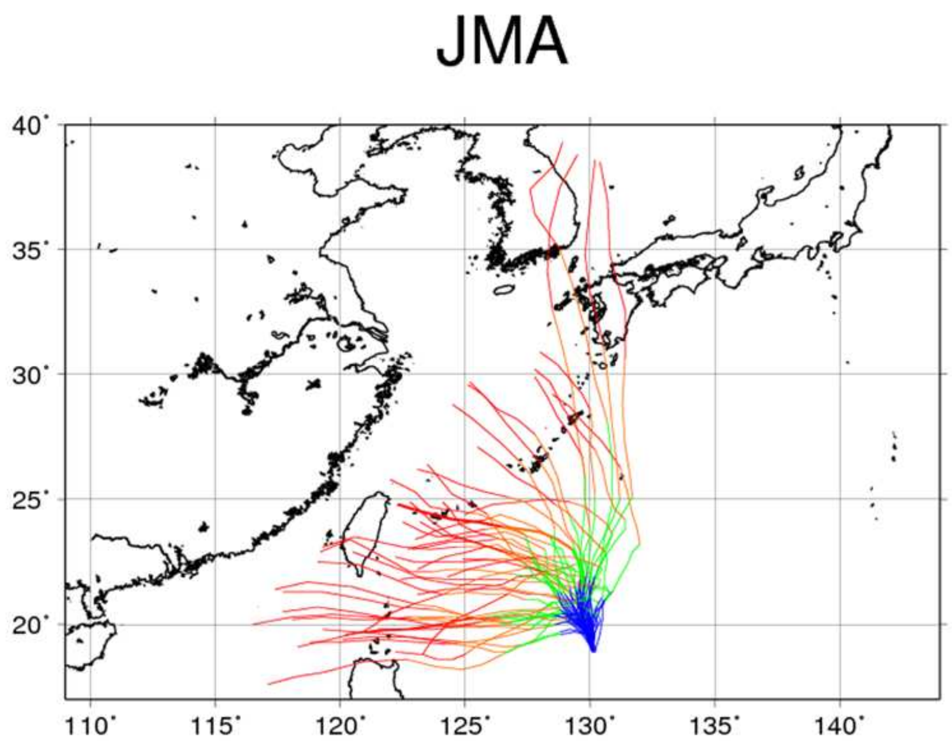
MCGE



Black line is the observed track.
The number on the black line indicates day(s) from the initial date.

Track Prediction for Typhoon FITOW (2013)




JMA
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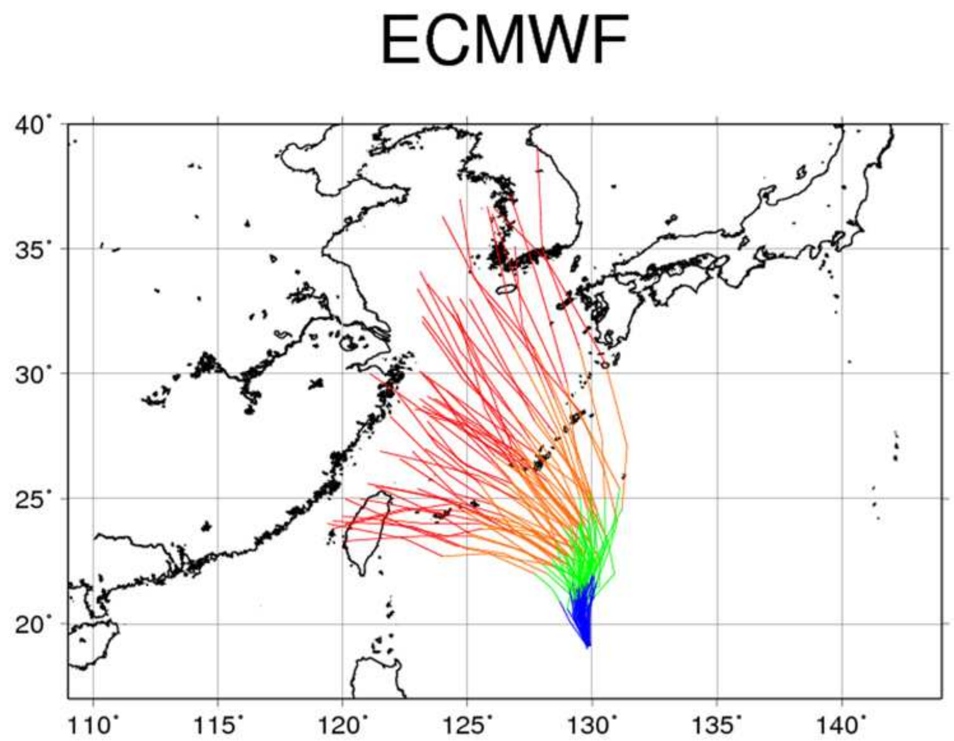
ECMWF
40°
35°
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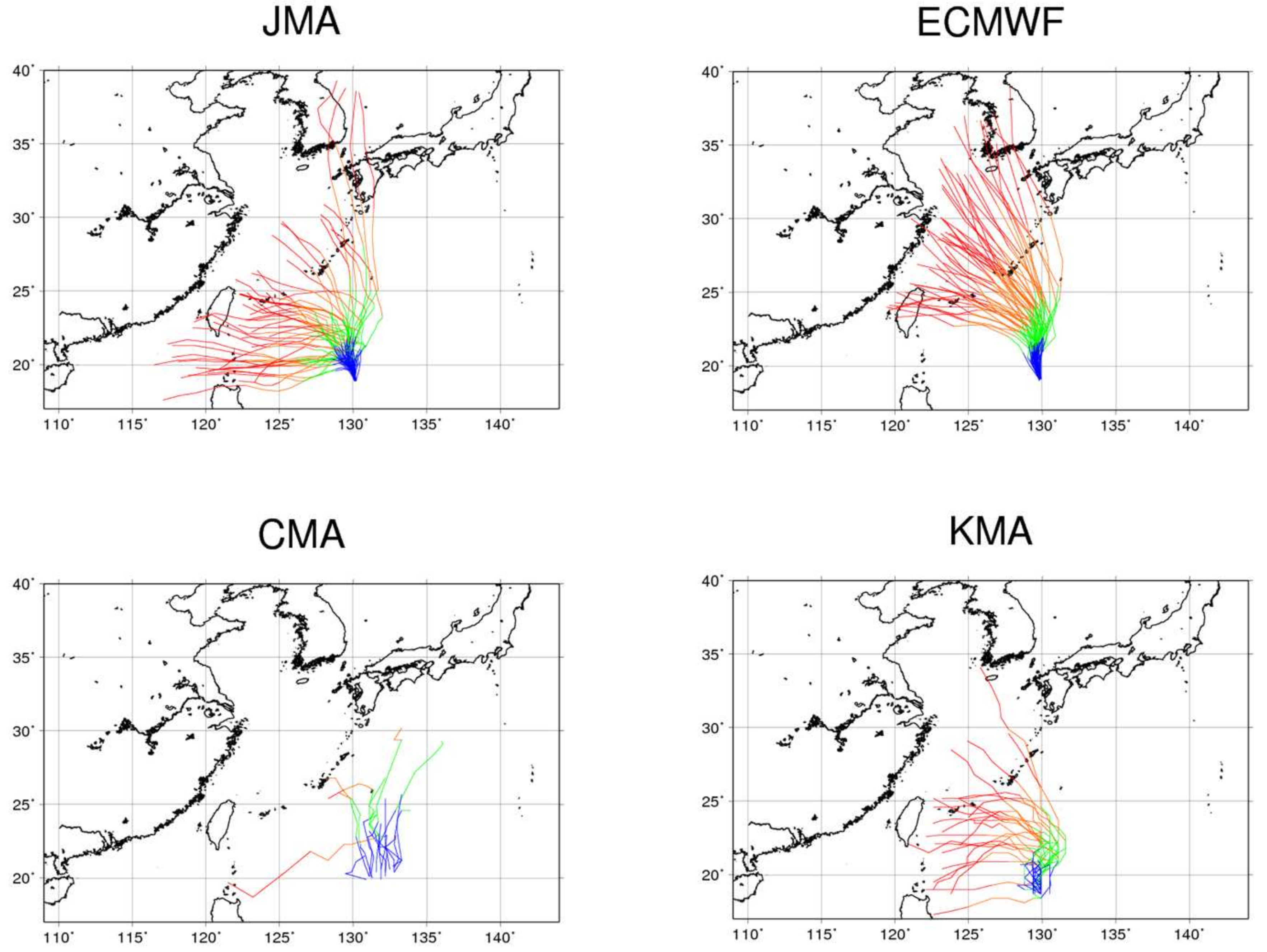
JMA
ECMWF
CMA
KMA
40°
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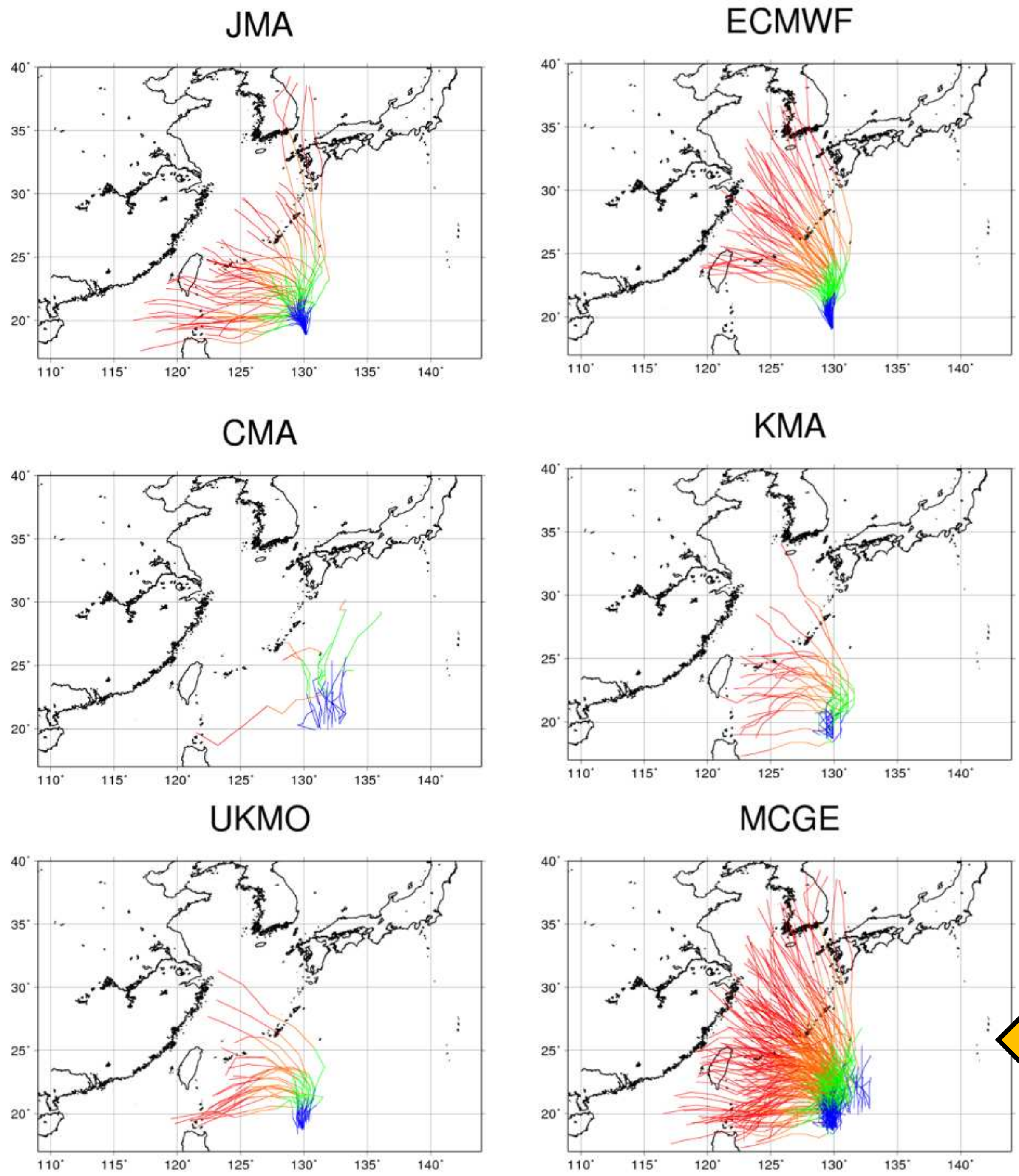

Ensemble Size =

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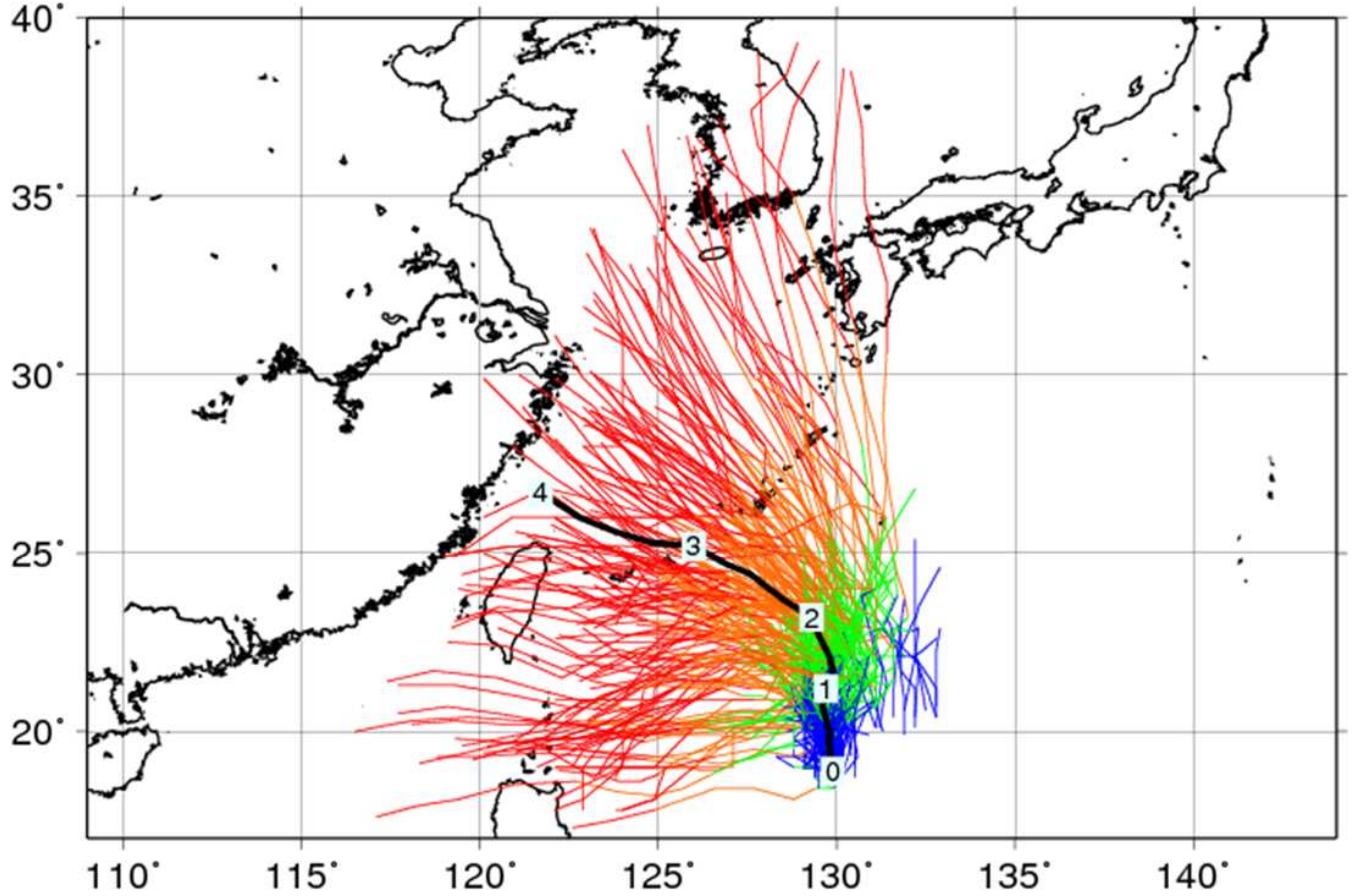
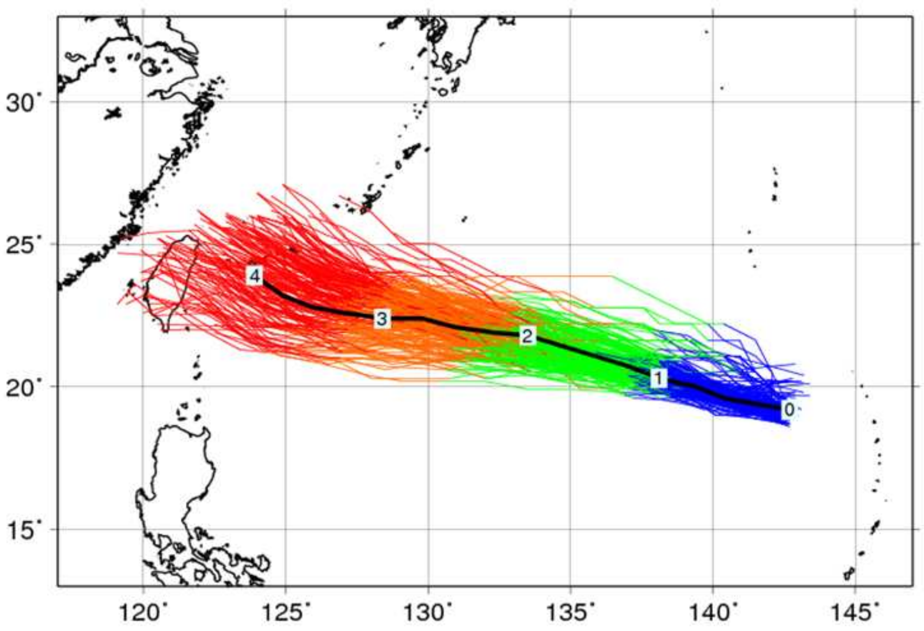
MCGE



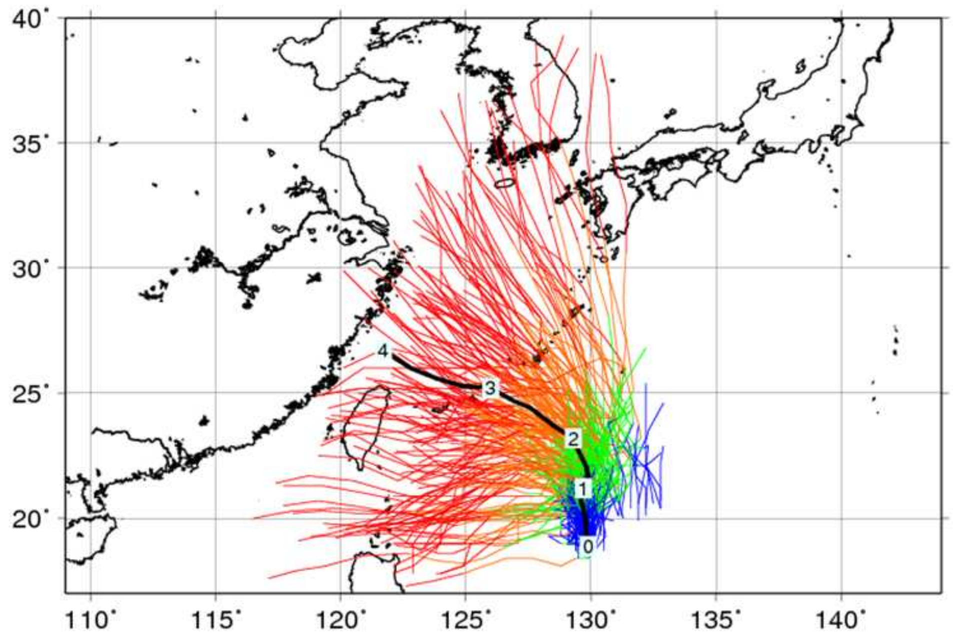
Black line is the observed track.
The number on the black line indicates day(s) from the initial date.

What is the benefit of using MCGE?

Typhoon SOULIK
Init.: 2013.07.08 12UTC



Typhoon FITOW
Init.: 2013.10.03 12UTC



MCGE products provide forecasters with additional information on the forecast uncertainty and increase the level of confidence in the forecast.

Systematic verification of MCGE

The relative benefits of MCGE over single model ensemble (SME) are investigated from both deterministic and probabilistic perspectives. 58 TCs in the western North Pacific from 2008 to 2010 are verified.

1. TC strike probability

   Reliability is improved in MCGE, especially in the high-probability range. MCGE reduces the missing area by about 10 %.

2. Confidence information

   When multiple SMEs simultaneously predict the low uncertainty, the confidence level increases and a chance to have a large position error decreases.

3. Ensemble mean track prediction

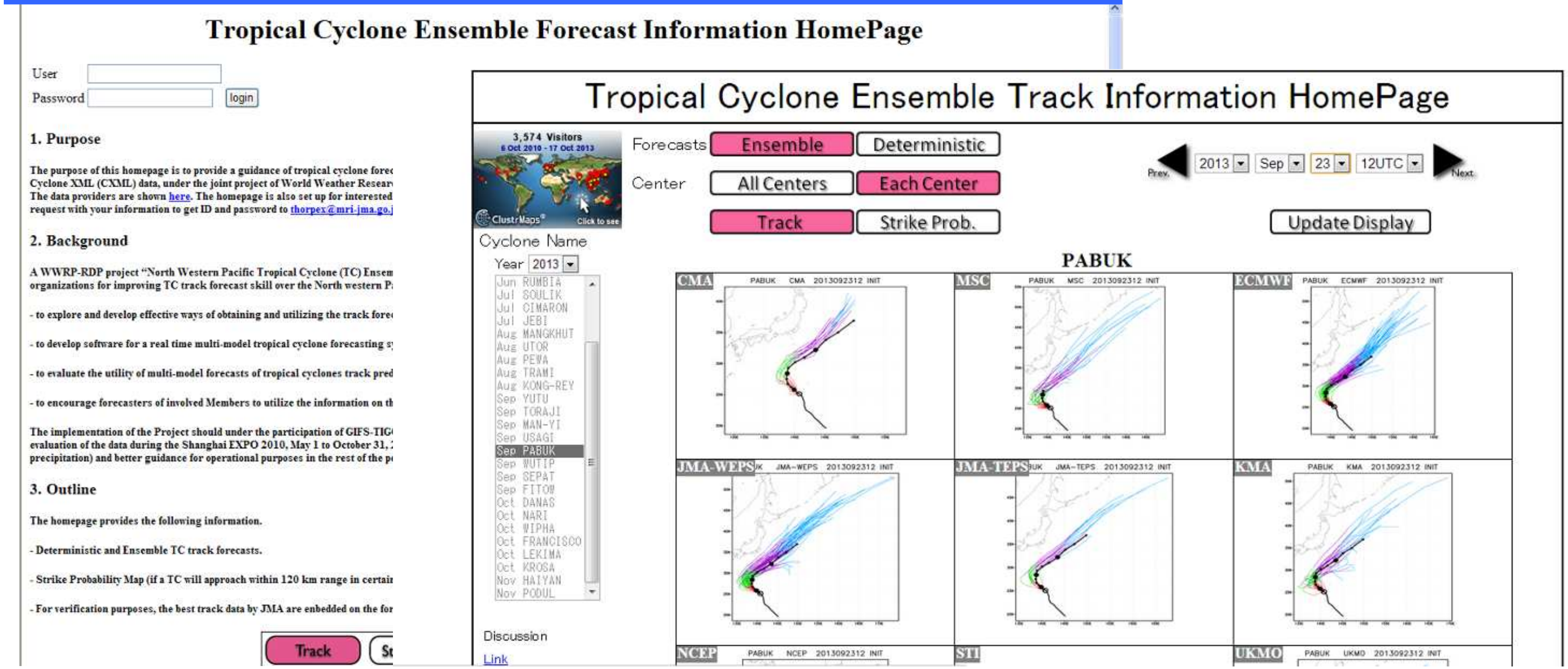
   The position errors of 5-day predictions by the MCGE-3 are slightly smaller than that of the ensemble mean of the best SME although the difference is not statistically significant.

Yamaguchi, M., T. Nakazawa, and S. Hoshino, 2012: On the relative benefits of a multi-centre grand ensemble for tropical cyclone track prediction in the western North Pacific, *Q.J.R. Meteorol. Soc.*, 138, 2019-2029.

NWP-TCEFP website

MRI/JMA operates a website of NWP-TCEFP where the MCGE products of TC tracks are available.

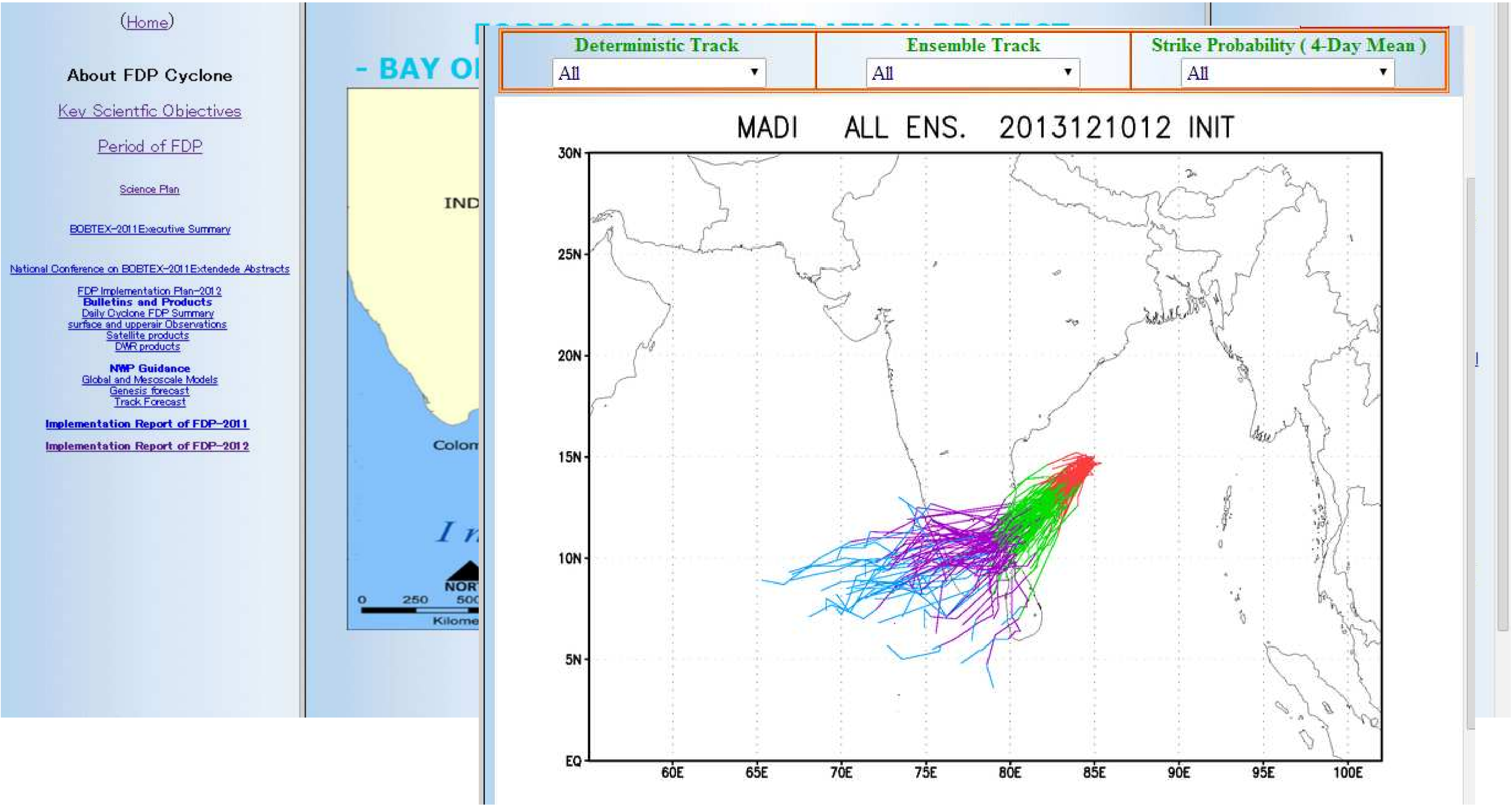
Main Page
(http://tparc.mri-jma.go.jp/cyclone/login.php)



Send e-mail to thorpex@mri-jma.go.jp to get ID and password

Bay of Bengal Tropical Cyclone Experiment

NWP-TCEFP website have been transferred to the Indian Meteorological Department website.

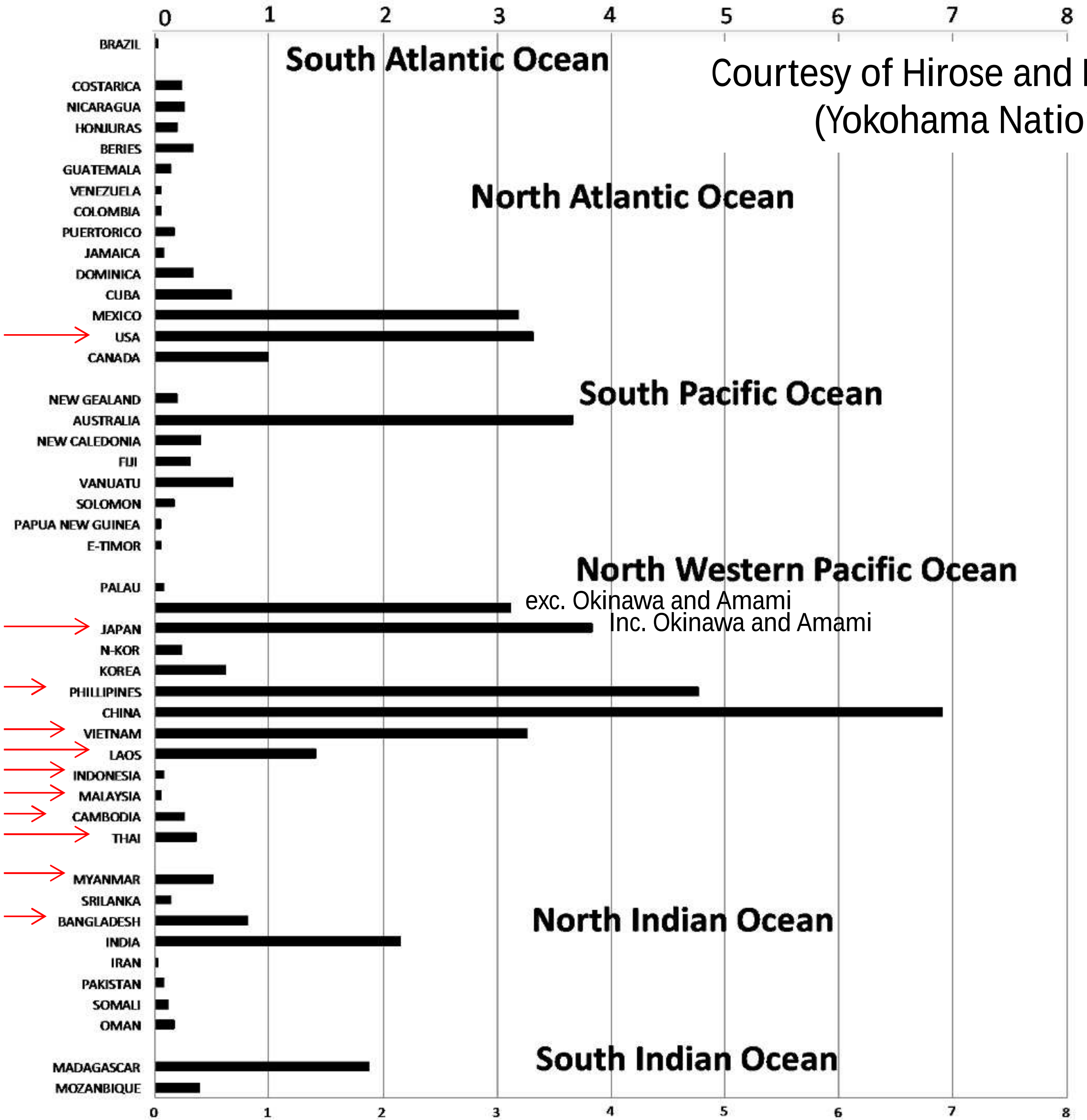


http://www.imd.gov.in/section/nhac/dynamic/cyclone_fdp/CycloneFDP.htm

Ensemble tropical cyclone activity prediction

Average number of TCs making landfall over a country in a year

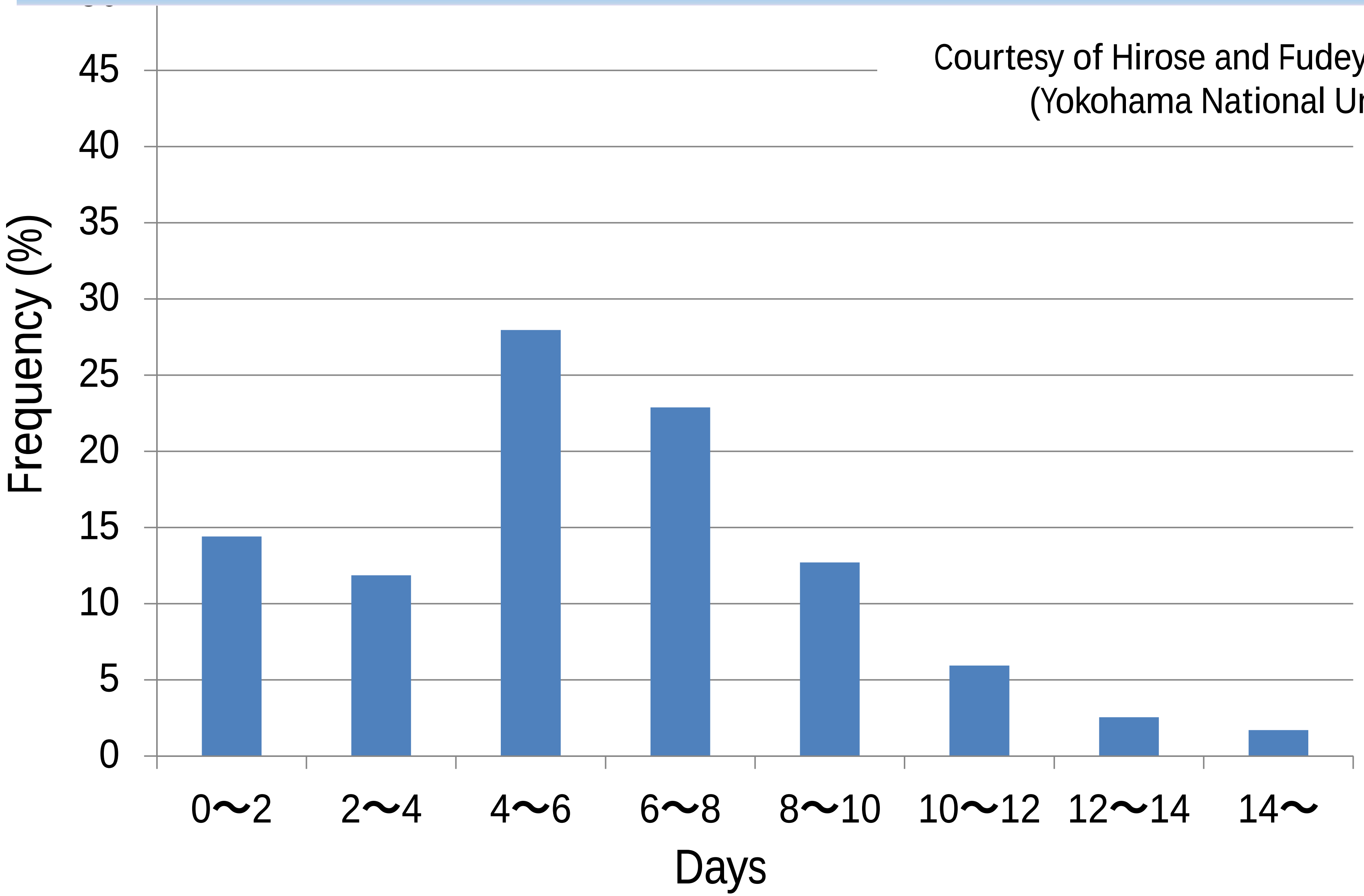
(Note that the number is calculated using IBTrACS from 197-2011, so it can be different from the official number)



Courtesy of Hirose and Fudeyasu (Yokohama National Univ.)

Frequency of days from TC genesis to the landfall
-Japan-

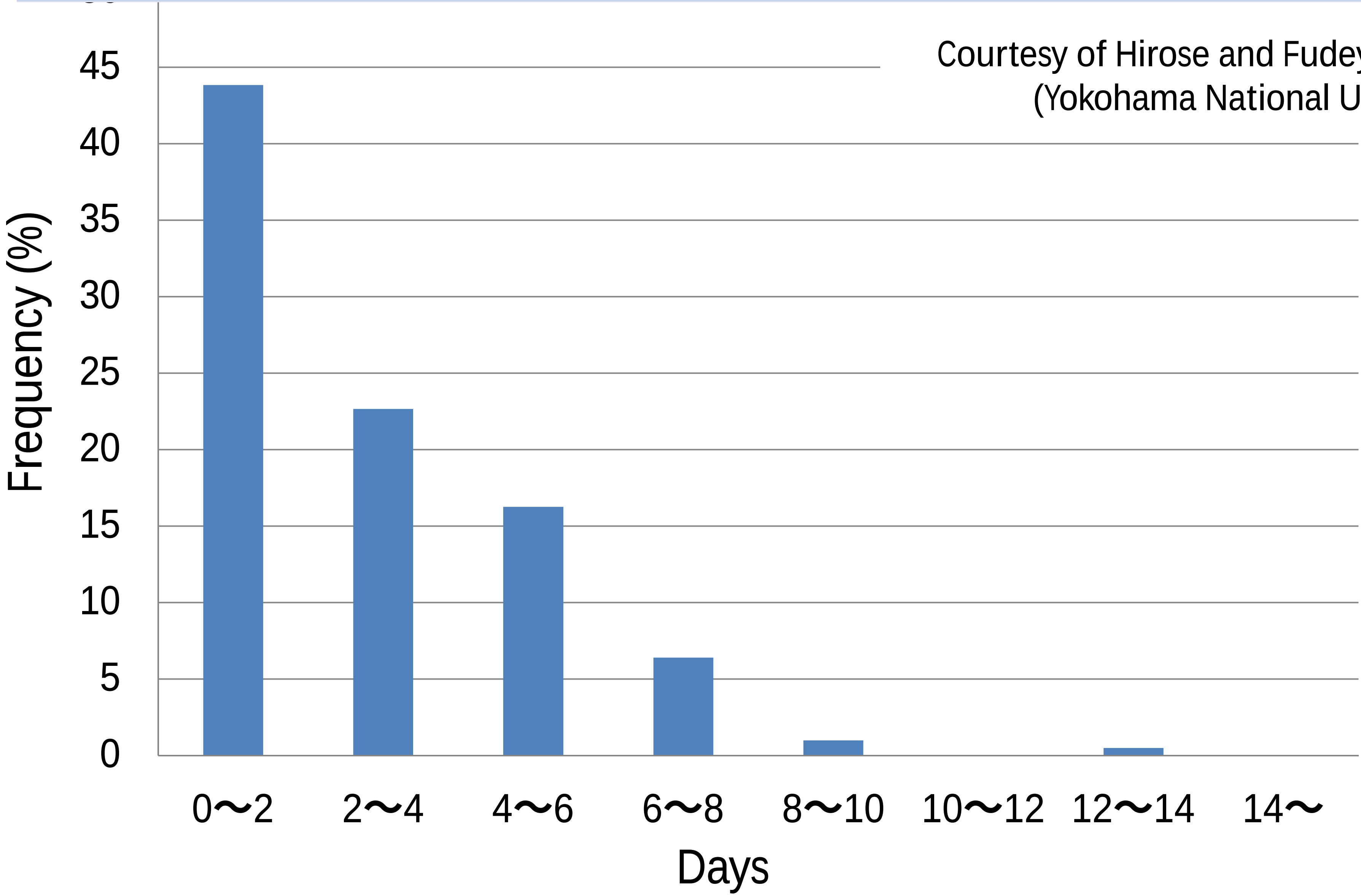
Courtesy of Hirose and Fudeyasu
(Yokohama National Univ.)



Frequency of days from TC genesis to the landfall

-Philippines-

Courtesy of Hirose and Fudeyasu
(Yokohama National Univ.)



Verification of Tropical Cyclone Activity Prediction -description-

- Although the performance of ensemble TC predictions has been studied well, the verification samples are usually limited to prediction cases where TCs exist at the initial times (i.e. TC strike probability prediction).

- There are few studies that verify TCs created during the model integrations on the medium-range time scale (i.e. TC genesis prediction).

- Systematic verification of ensemble TC predictions on the short- to medium-range time scale (1 – 14 days) has not been performed yet.

- In this study, ensemble predictions of TC activity for a certain domain is verified using TIGGE from ECMWF, JMA, NCEP and UKMO.

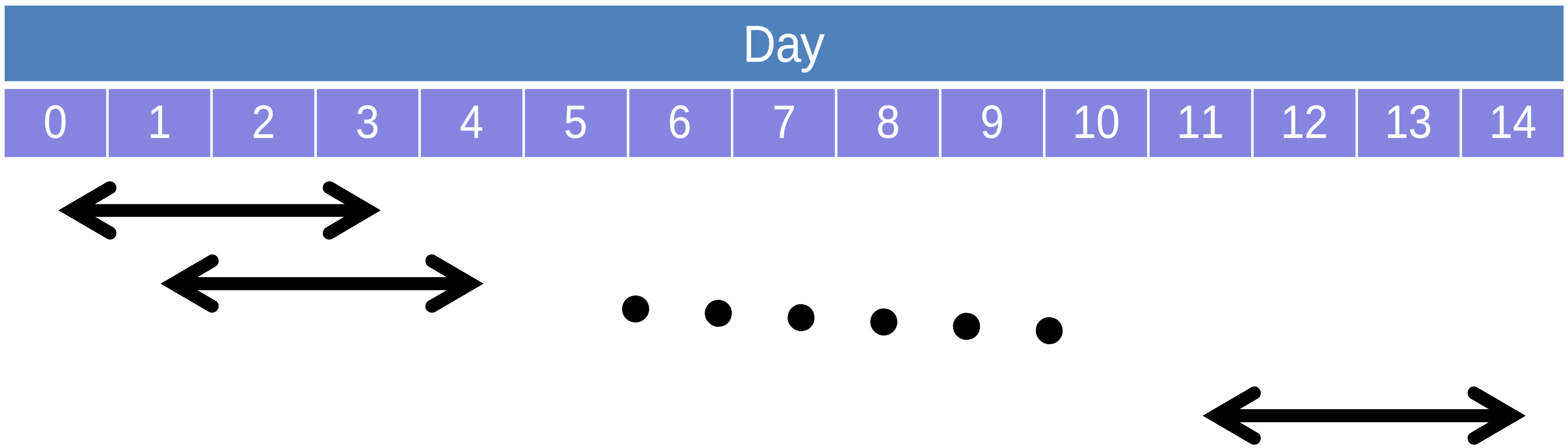
This study is one of the annual operating plans (AOPs) of the Working Group on Meteorology (WGM) for 2013.

Verification method

- Create TC tracking data using the ECMWF vortex tracker (Vitart et al. 1997, J. of Climate ; Vitart et al. 2007, ECMWF Newsletter).

- Verification period is July – October in 2010 to 2012. Verified TCs are TCs with a Tropical Storm intensity or stronger (35 knots or stronger).

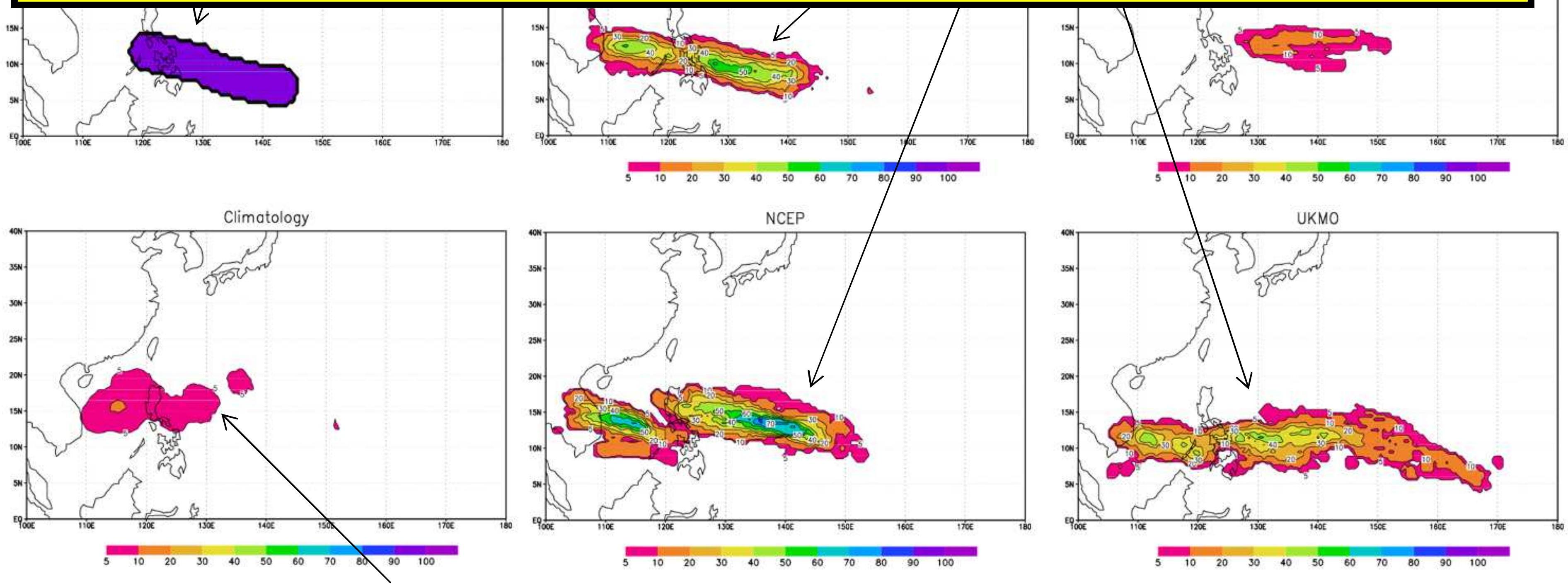
- Verify ensemble predictions of TC activity within a 3 day time window, which is applied over a forecast length of 2 weeks.



Example: TC activity probability maps -Haiyan-

- Initial time of the forecasts: 2013/10/31 12 UTC (about 4 days before the genesis and 8 days before the landfall over the Philippines)
- Time window: 2013/11/05 12 UTC – 2013/11/08 12 UTC (T+5days – T+8days)

- Probabilities are calculated at each grid point of a 0.5 x 0.5 deg. grid space
- A threshold distance of 300km is used to determine whether observed or forecast TCs affect a grid point.



Climatological TC activity of this initial time and this forecast time window

Brier Score

$$\text{Brier Score (BS)} = \frac{1}{N}\sum_{i=1}^{N}(f_i - o_i)^2$$

N: Number of samples

f_i: forecast probability (e.g. 0, 0.1, 0.2 .....0.9, 1)

o_i: o_i is 1 when the event occored and 0 otherwise

The BS is a negatively oriented score (smaller is better).
BS = 0 means the predictions are perfect.

$$\text{Brier Skill Score (BSS)} = 1 - BS/BS_{climatology}$$

The BSS is a positively oriented score (larger is better).
BS < 0 means the predictions are not skillful with respect to climatological.

Why “activity” prediction, not “genesis” prediction?

- In general TCs in models are weaker than those in reality. This tread is strong for ensemble predictions because the horizontal resolution for them is generally low.

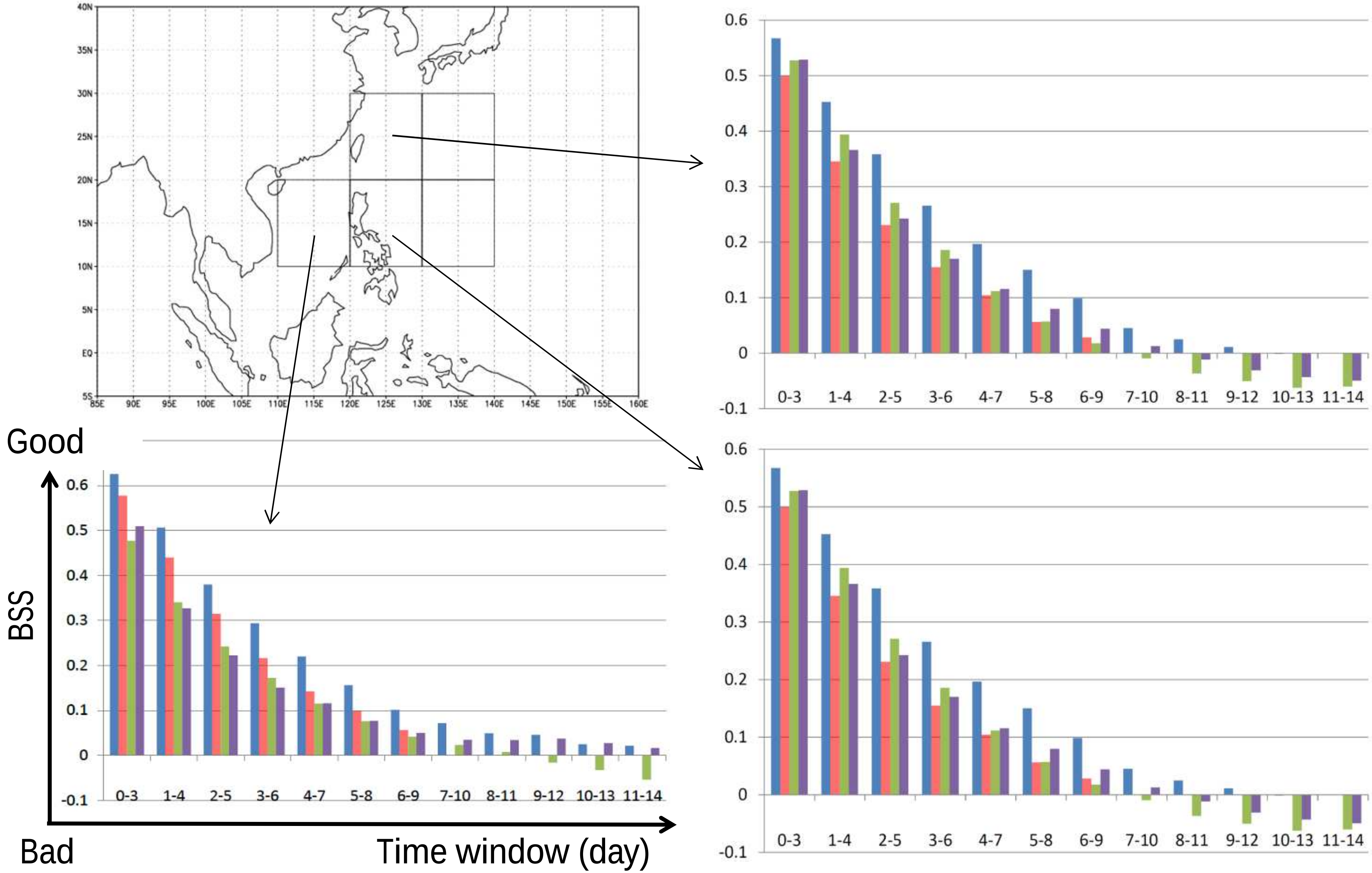
- It is difficult to say exactly when we can regard model TCs as TCs with a maximum sustained wind of 35 knots or more.

- Given that the average lifetime of TCs is about 5 days, verifications with a time wind of 5 days or longer could be regarded as verifications of TC genesis and the subsequent track.

- After all, what people are interested in is whether or not TCs exist in a certain domain in a certain forecast time or time window.

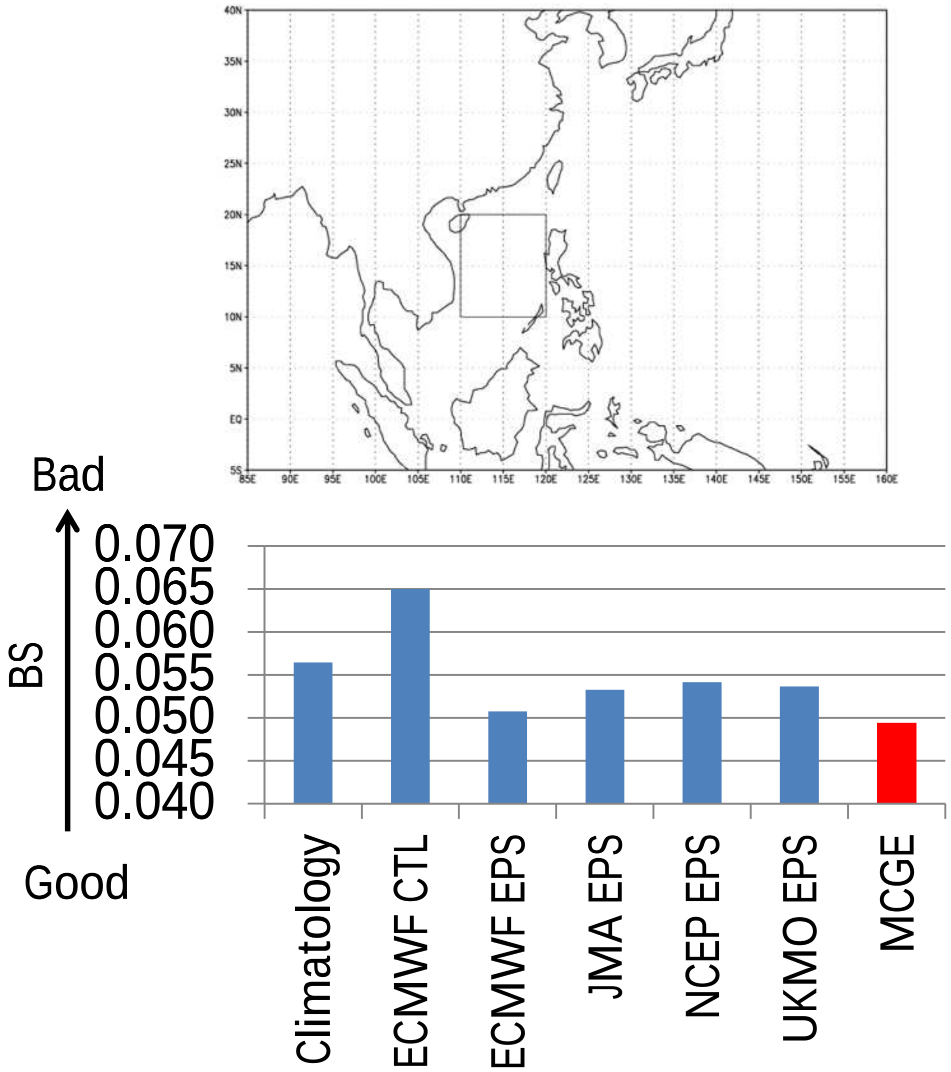
Verification of Tropical Cyclone Activity Prediction

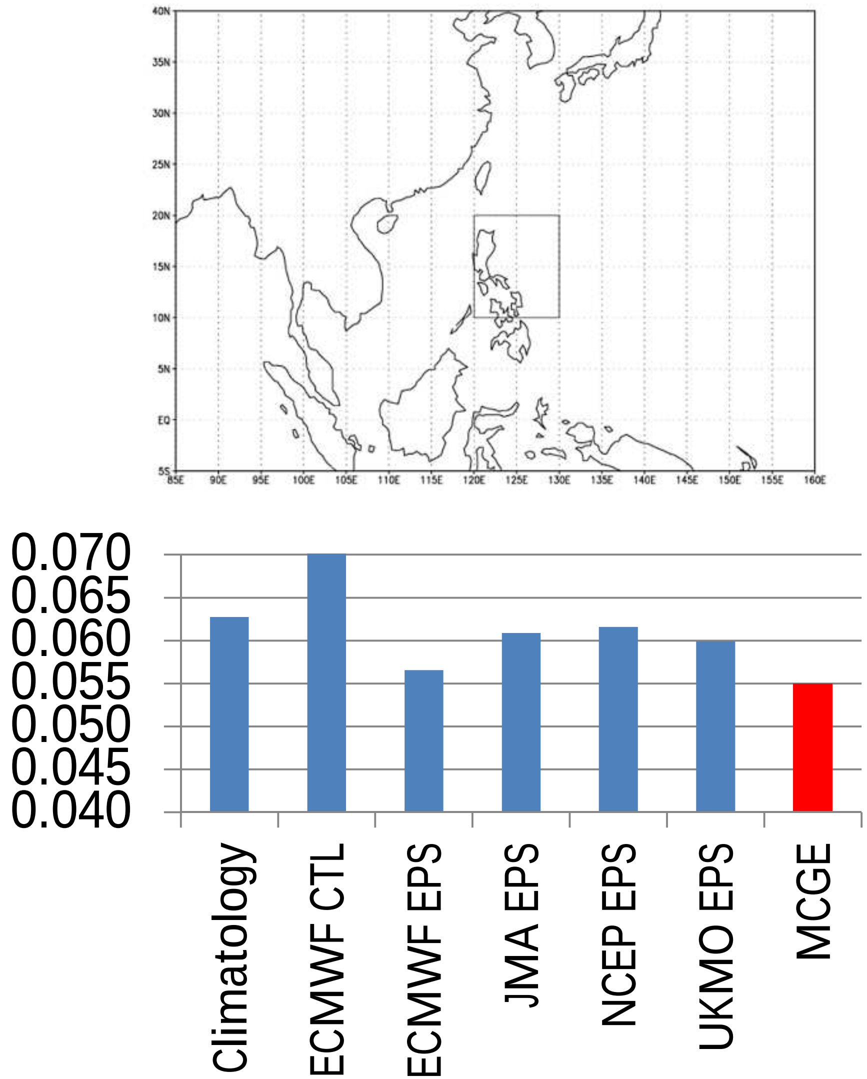
Blue: ECMW, **Red**: JMA (up to 9 days), **Green**: NCEP, **Purple**: UKMO



Benefits of MCGE

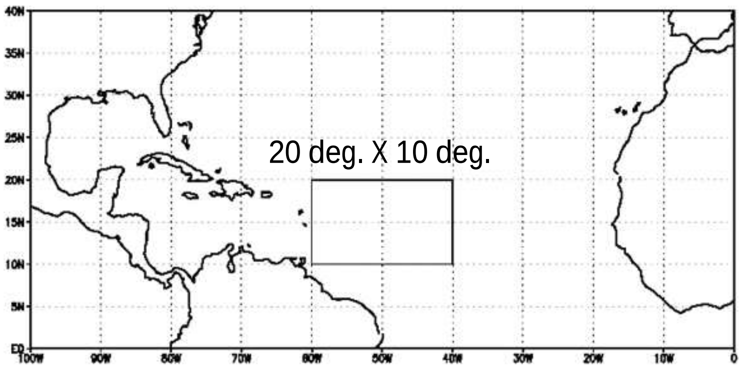
Verification for a time window of T+6 – T+9 days

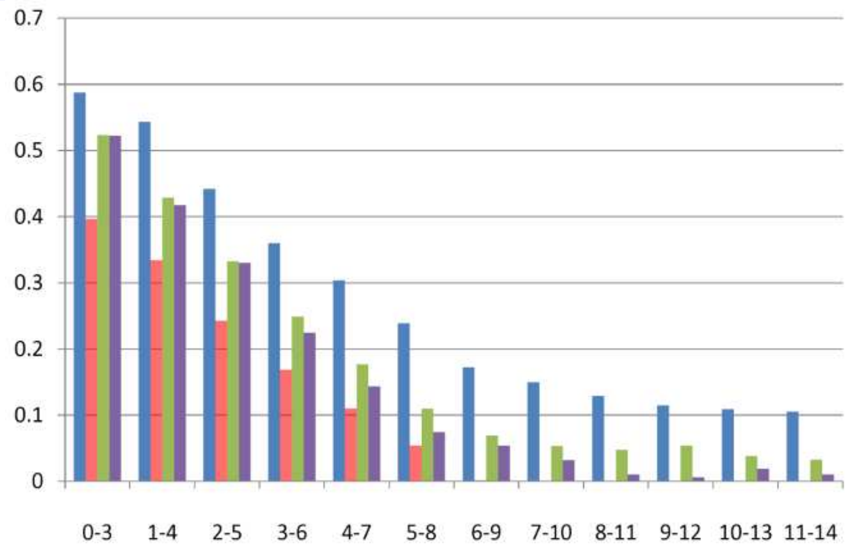




Future studies

•Extend the verification into the globe.





The same color bar definition as slide 28

•In verification for individual TC cases, all EPSs are successful in predicting genesis events with a lead time of 5 days or longer in some cases (e.g. Typhoon SON-TINH in 2012), while cases with less predictability also exist (e.g. Typhoon NALGAE in 2011). Investigate the difference in the predictability from the synoptic environment.

Evaluation of TC activity in the North Indian Ocean using ECMWF ensemble

TABLE 1. BSS and ROC score (ROCS) for the Arabian Sea and the Bay of Bengal based on VarEPS forecasts for TC activity during the months of April–June and August–December during 2007–10. BSS (ROCS) in boldface are statistically different from 0 (0.5) at the 95% confidence level.

Arabian Sea	BSS	ROCS
All forecast days	**0.17**	**0.82**
Forecast days ≤ 2	**0.47**	**0.85**
Forecast days 2–5	**0.32**	**0.87**
Forecast days 5–10	0.04	**0.82**
Forecast days 10–15	−0.14	**0.70**
Bay of Bengal	BSS	ROCS
All forecast days	**0.09**	**0.80**
Forecast days ≤ 2	**0.30**	**0.77**
Forecast days 2–5	**0.16**	**0.79**
Forecast days 5–10	**0.16**	**0.82**
Forecast days 10–15	−0.02	**0.74**

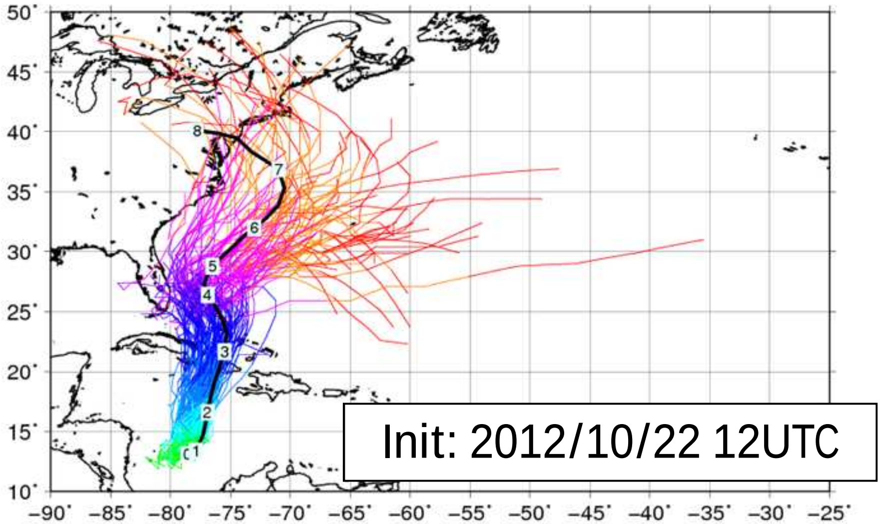
Belanger, James I., Peter J. Webster, Judith A. Curry, Mark T. Jelinek, 2012: Extended prediction of north indian ocean tropical cyclones. *Wea. Forecasting*, **27**, 757–769.

Hurricane Sandy, Cyclone Phailin and Typhoon Haiyan

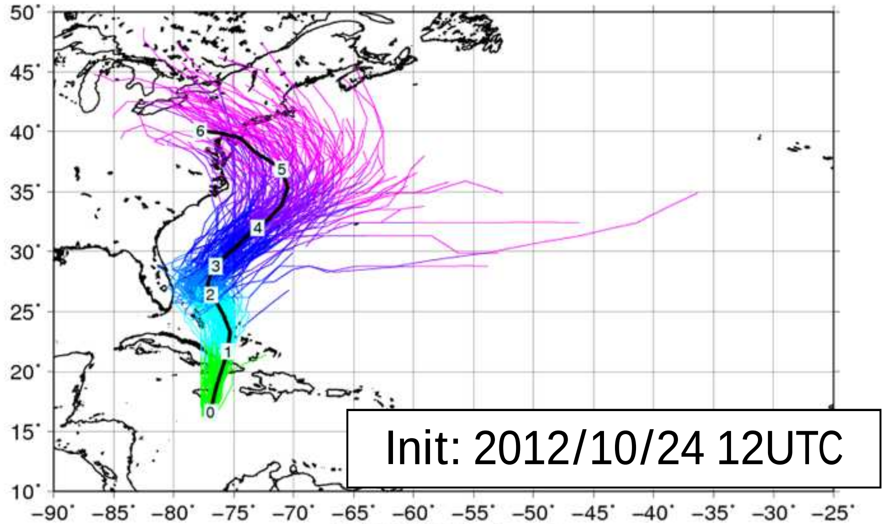
images are taken from wikipedia and bbc.co.uk

Hurricane Sandy (2012)

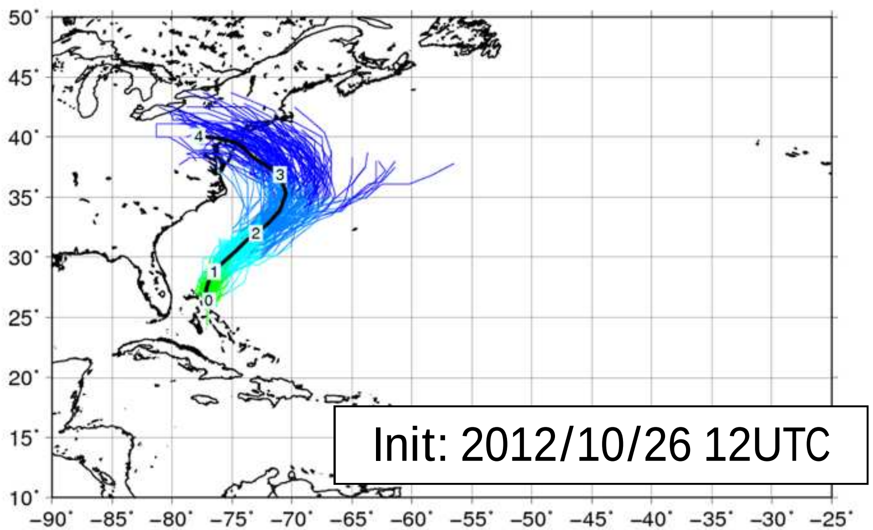
MCGE−4



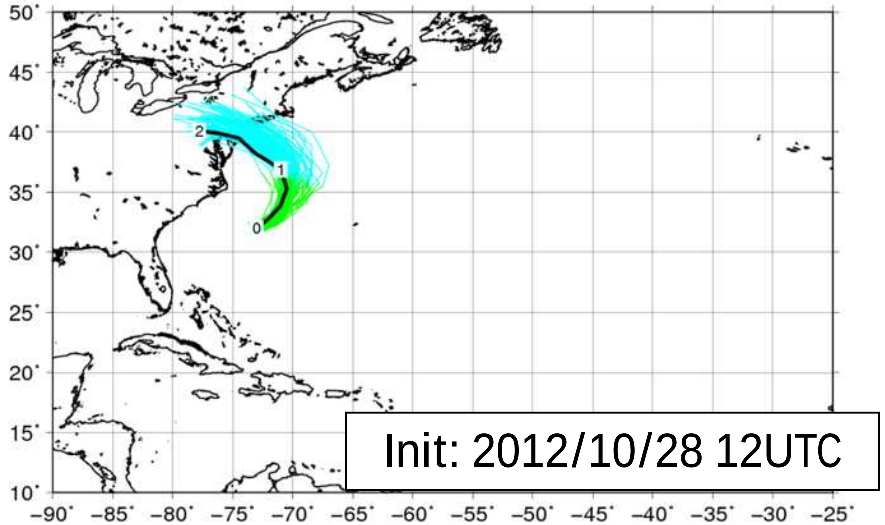
MCGE−4



MCGE−4

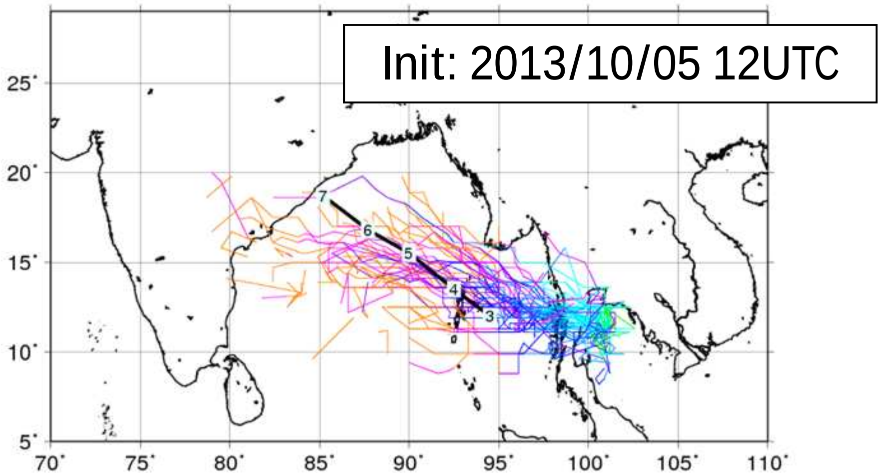


MCGE−4

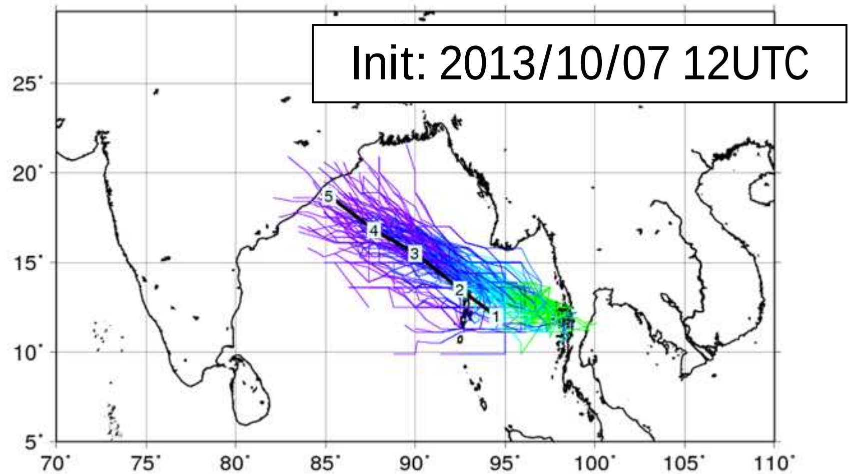


Cyclone Phailin (2013)

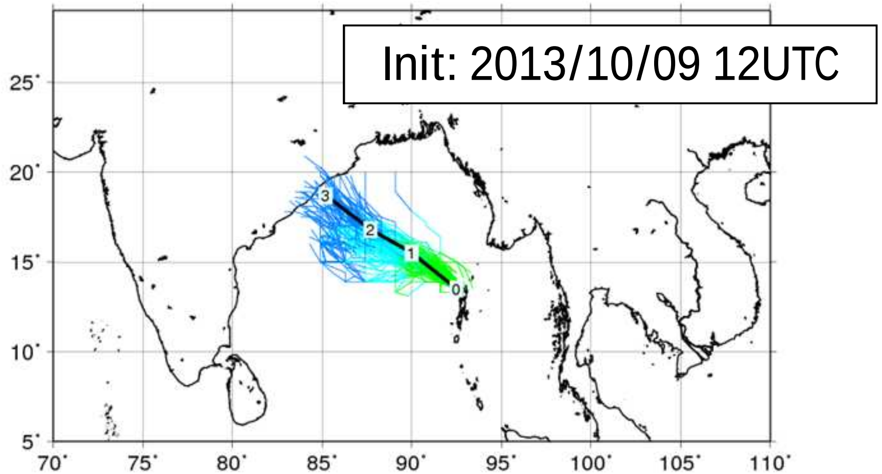
MCGE–4



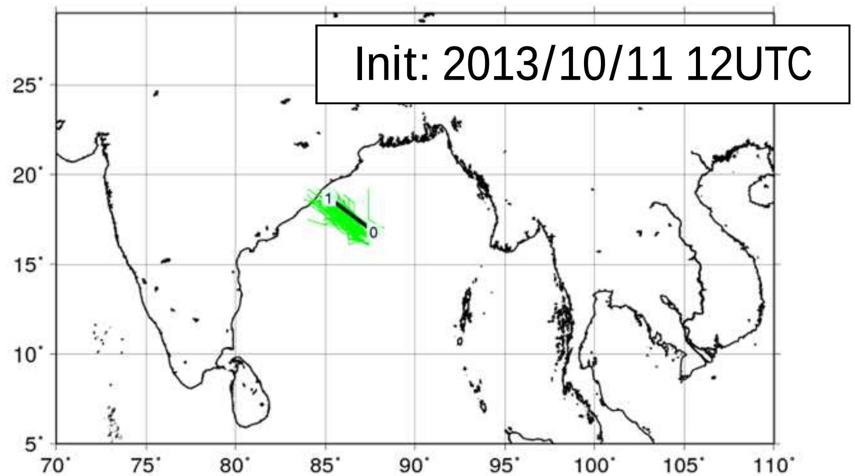
MCGE–4



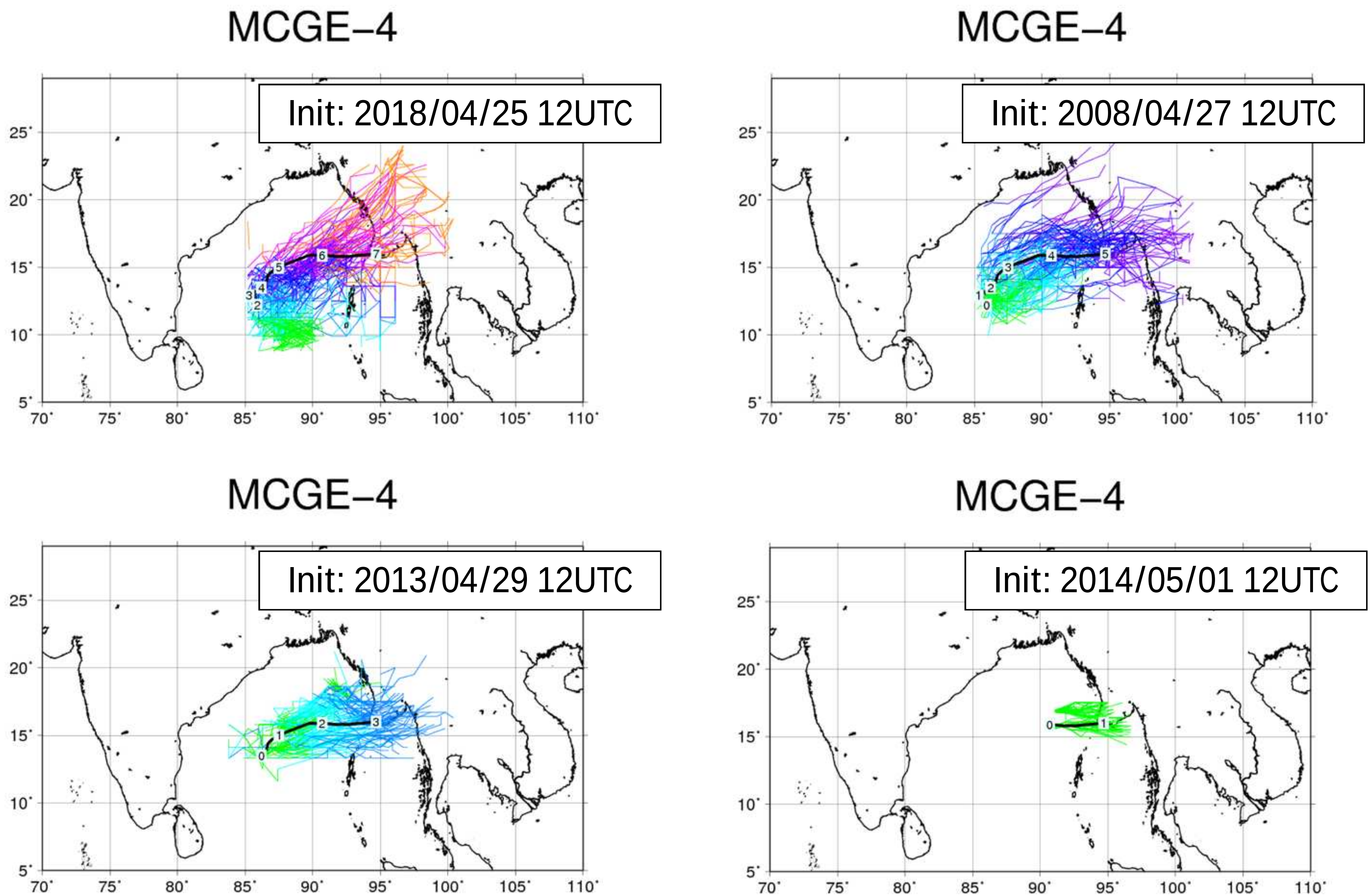
MCGE–4



MCGE–4

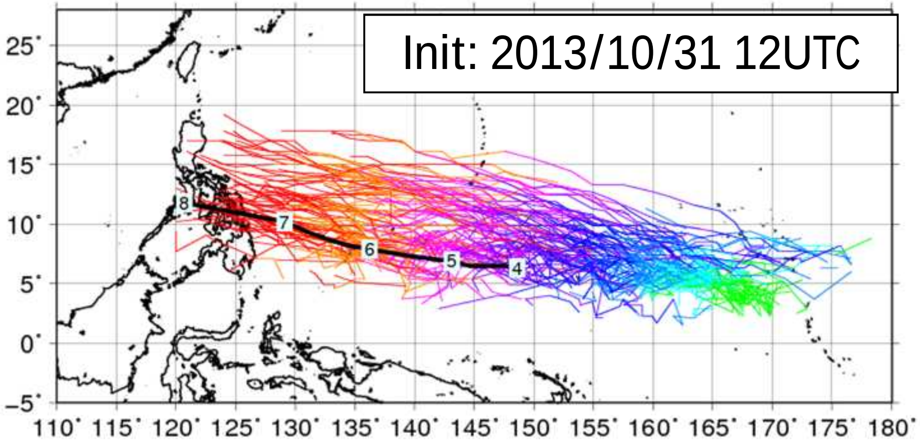


Cyclone Nargis (2008)

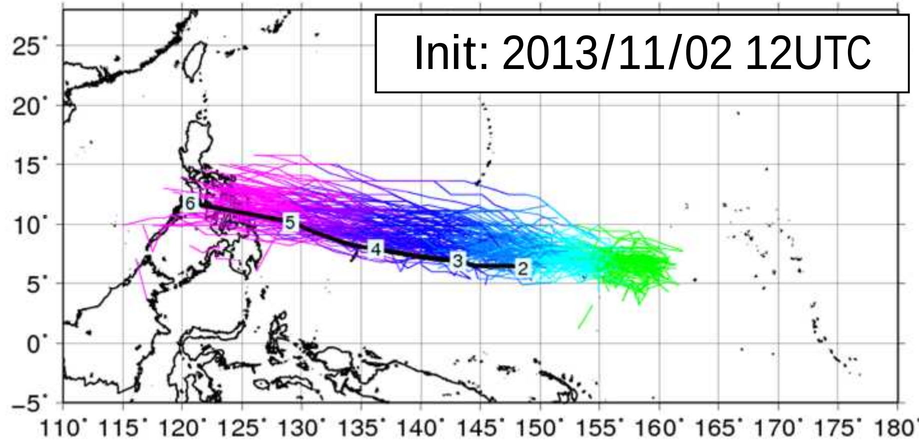


Typhoon Haiyan (2013)

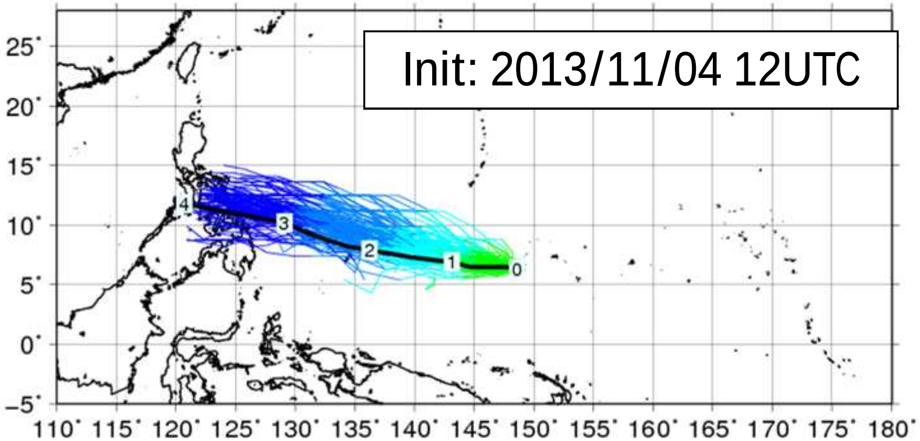
MCGE–4



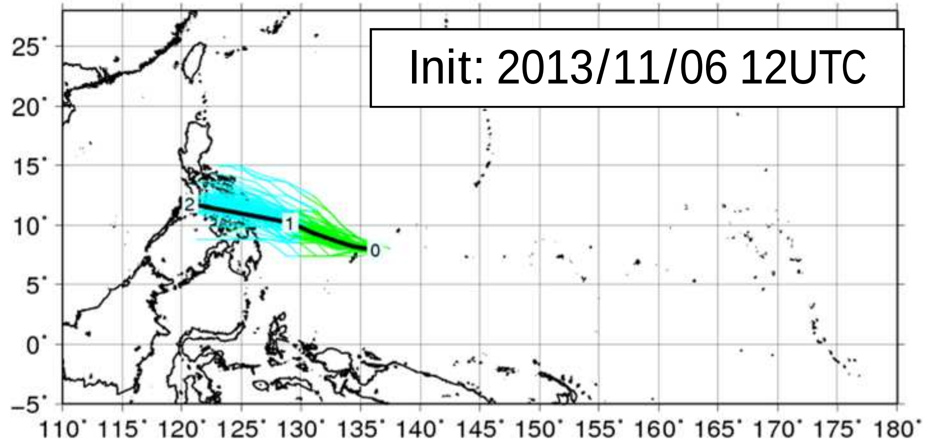
MCGE–4



MCGE–4



MCGE–4



Summary

- For TC track forecasts, MCGE products provide forecasters with additional information on the forecast uncertainty and increase the level of confidence in the forecast.

- TC activity predictions are evaluated using TIGGE data from ECMWF, JMA, NCEP and UKMO.

  - Brier Skill Scores (BSSs) of all NWP centers are positive at least up to day 9, indicating more skillful predictions than the climatology.
  - MCGE is more skillful than the single-model ensemble.

- For recent high-impact TCs, Hurricane Sandy, Cyclones Phailin and Nargis, and Typhoon Haiyan, MCGE predicted the landfall with high-confidence at least 5 days before the landfall.

Supplementary slides

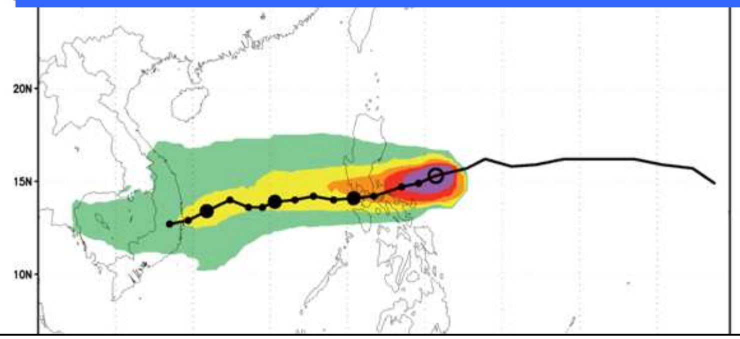
TC strike probability

Original idea by Van der Grijn (2002, ECMWF Tech. Memo):
"A forecaster is often more interested in *whether* a TC will affect a certain area than *when* that TC will hit a specific location."

He defined the strike probability as "the probability that a TC will pass within a 65 nm radius from a given location at **anytime** during the next 120 hours".

It allows the user to make a quick assessment of the high-risk areas regardless of the exact timing of the event.

Example
-TC strike probability map-

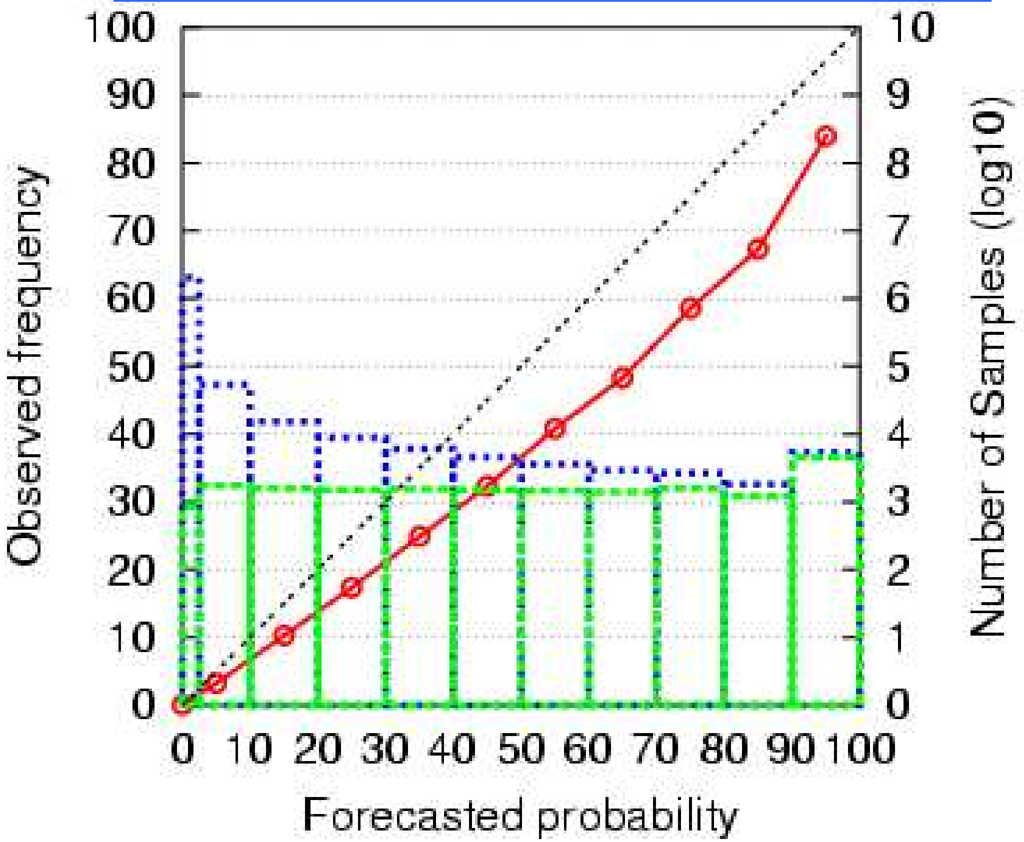


The strike probability is based on the number of members that predict the event with each member having an equal weight.

Verification result of TC strike probability -1-

Strike prob. is computed at every 1 deg. over the responsibility area of RSMC Tokyo - Typhoon Center (0°-60°N, 100°E-180°) based on the same definition as Van der Grijn (2002). Then the reliability of the probabilistic forecasts is verified.

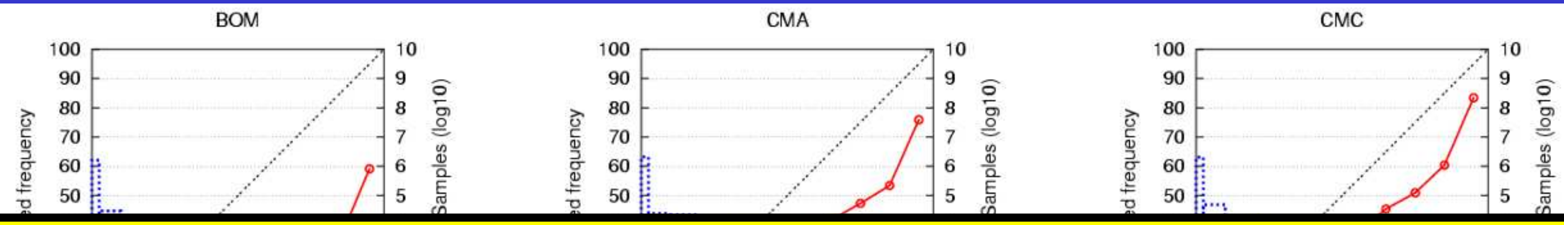
Reliability Diagram
-Verification for ECMWF EPS-



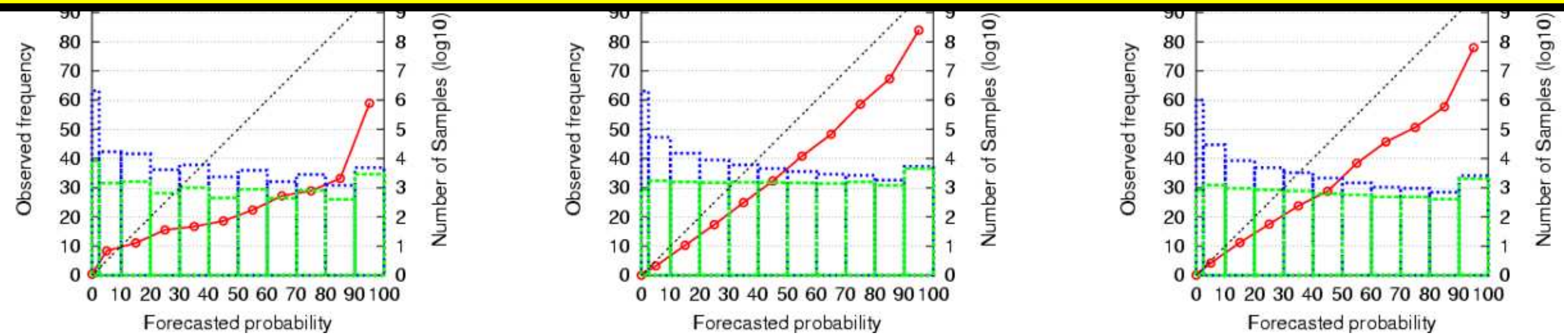
In an ideal system, the red line is equal to a line with a slope of 1 (black dot line).

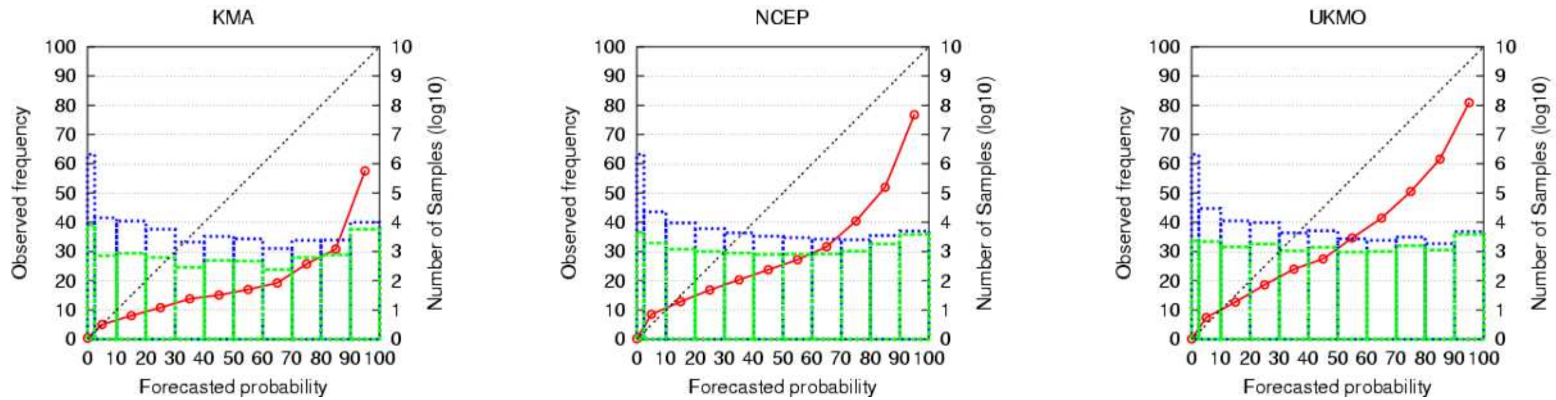
The number of samples (grid points) predicting the event is shown by **dashed blue boxes**, and the number of samples that the event actually happened is shown by **dashed green boxes**, corresponding to y axis on the right.

Verification result of TC strike probability -2-

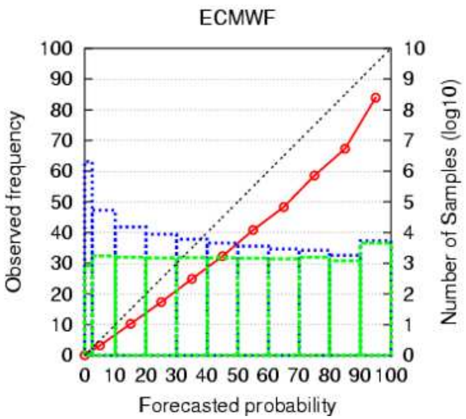


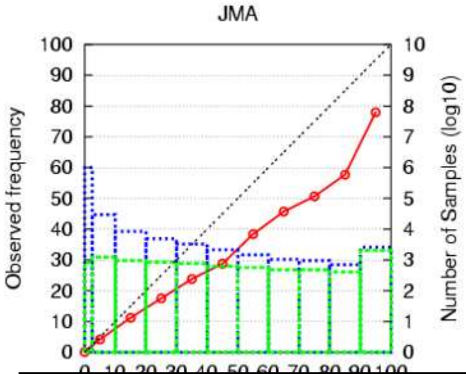
All SMEs are <u>over-confident</u> (forecasted probability is larger than observed frequency), especially in the high-probability range.

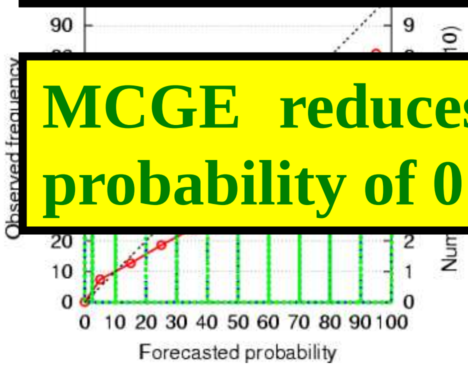




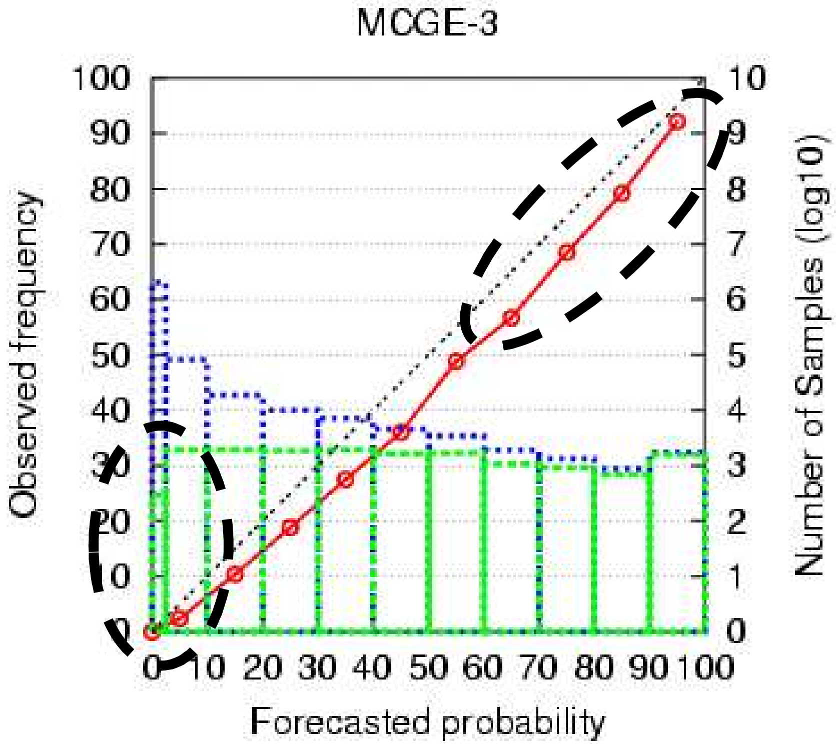
Benefit of MCGE over SME -1-







Combine 3 SMEs

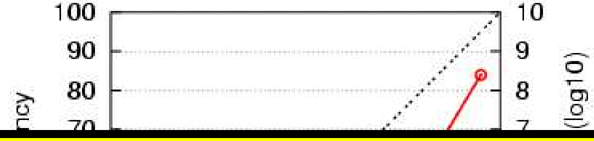


Reliability is improved, especially in the high-probability range.

MCGE reduces the missing area (see green dash box at a probability of 0 %).

Benefit of MCGE over SME -2-

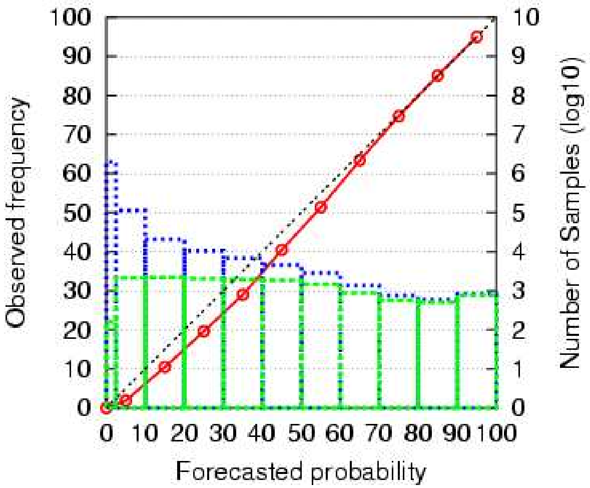
Best SME (ECMWF)



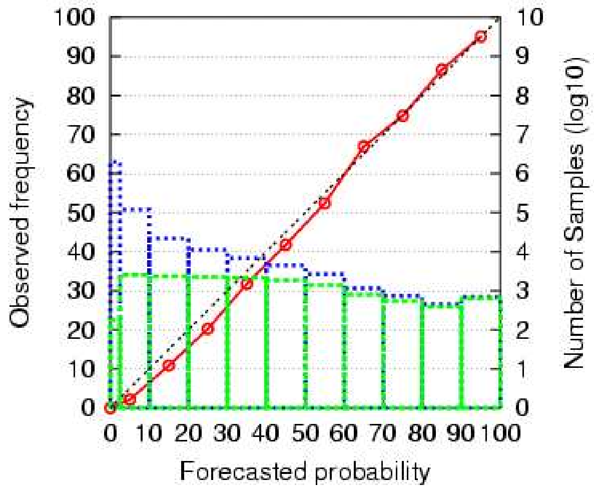
MCGE-3 (ECMWF+JMA+UKMO)

MCGEs reduce the missing area! The area is reduced by about 1/10 compared with the best SME. Thus the MCGEs would be more beneficial than the SMEs for those who need to avert missing TCs and/or assume the worst-case scenario.

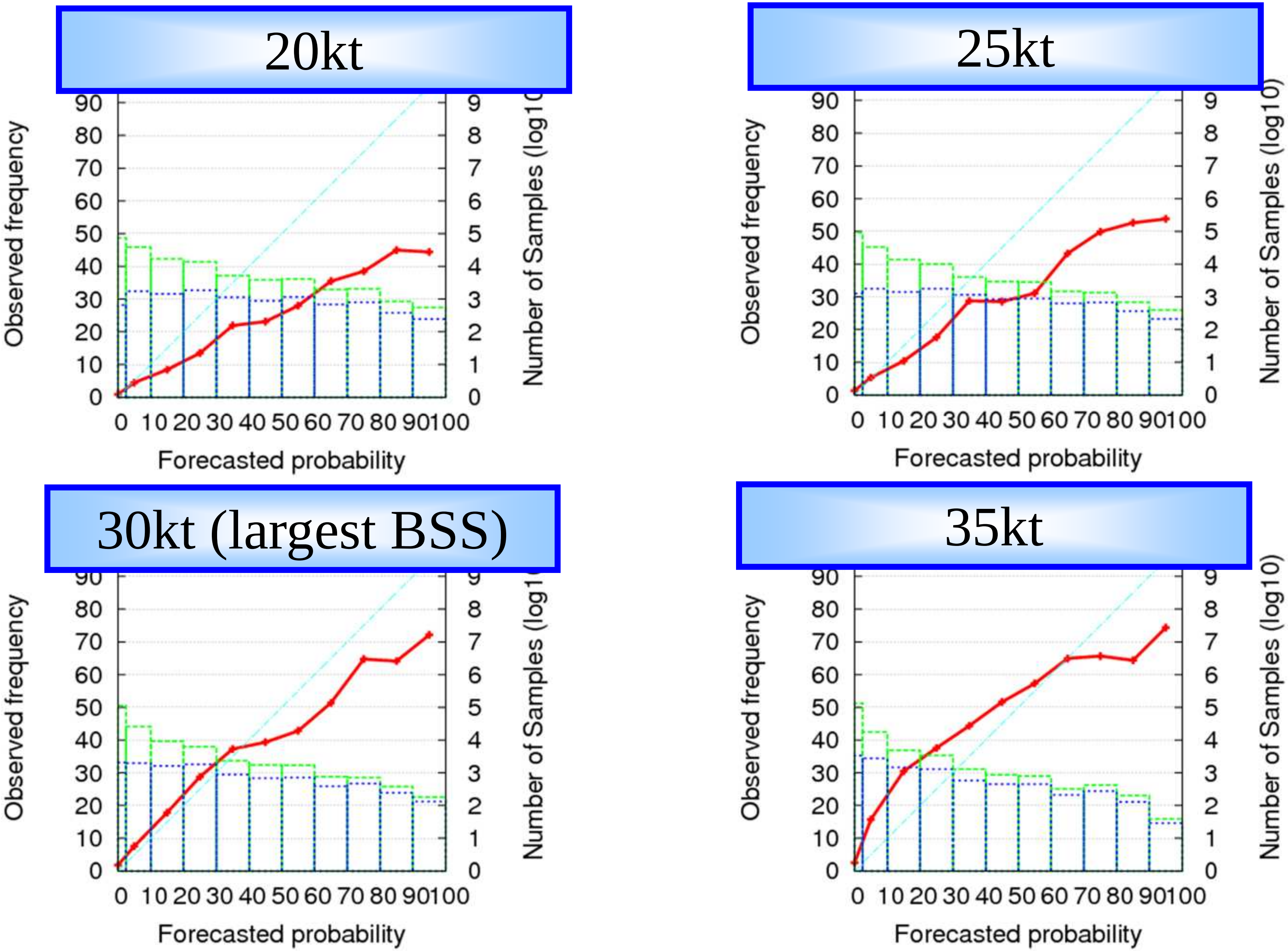
MCGE-6 (CMA+CMC+ECMWF+JMA+NCEP+UKMO)

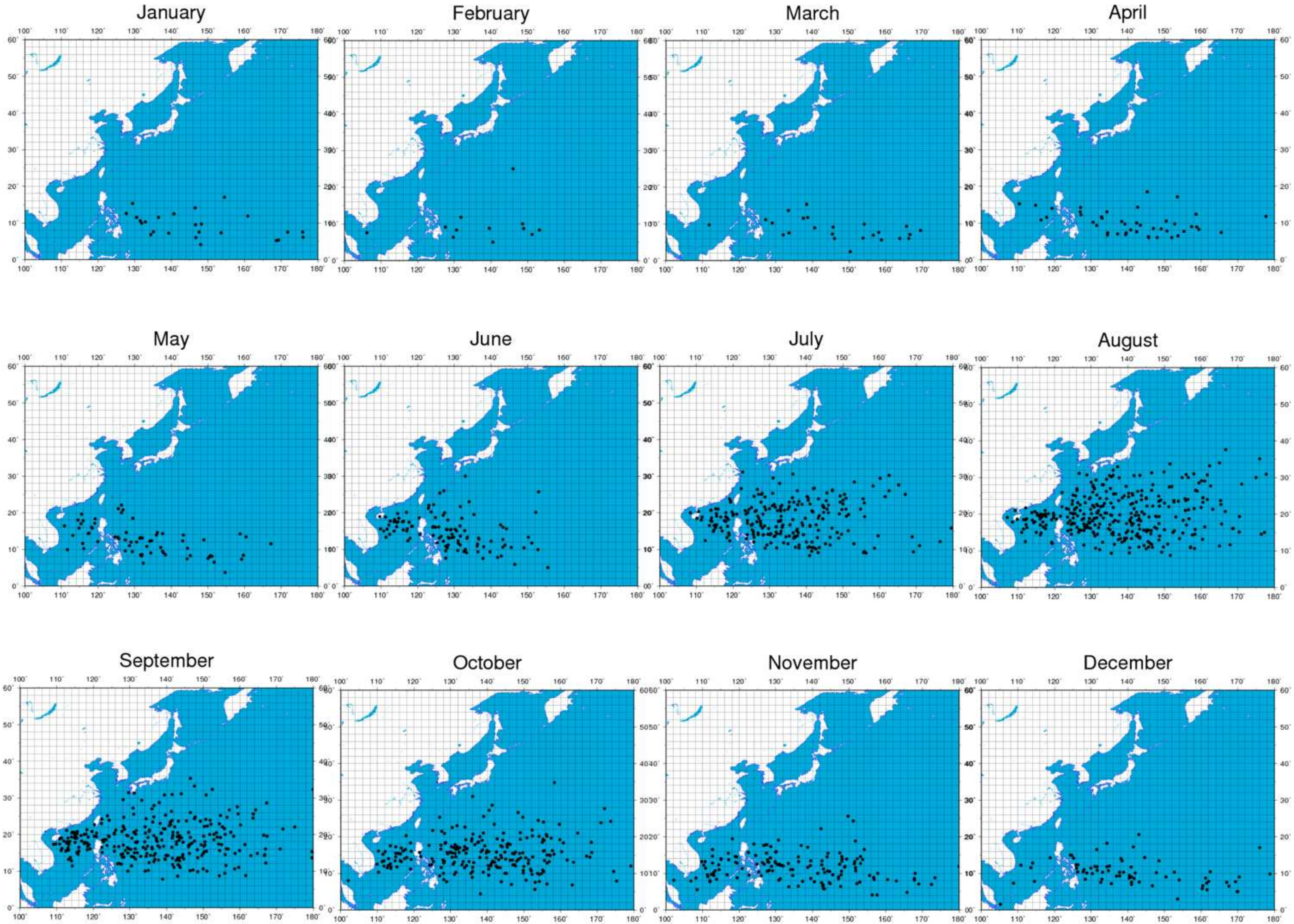


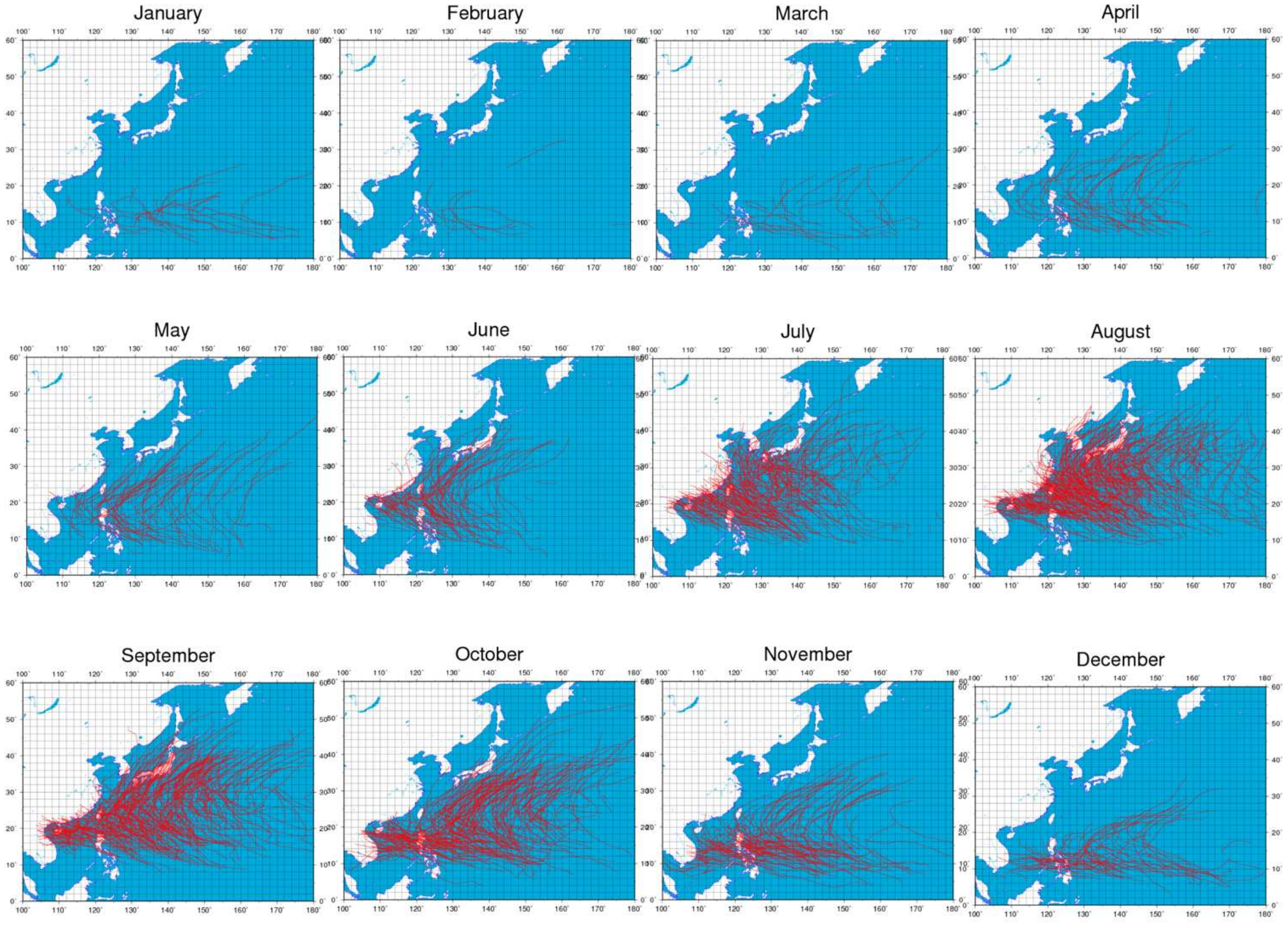
MCGE-9 (All 9 SMEs)



Reliability Diagram with different threshold (time window 3-6 days): AREA11

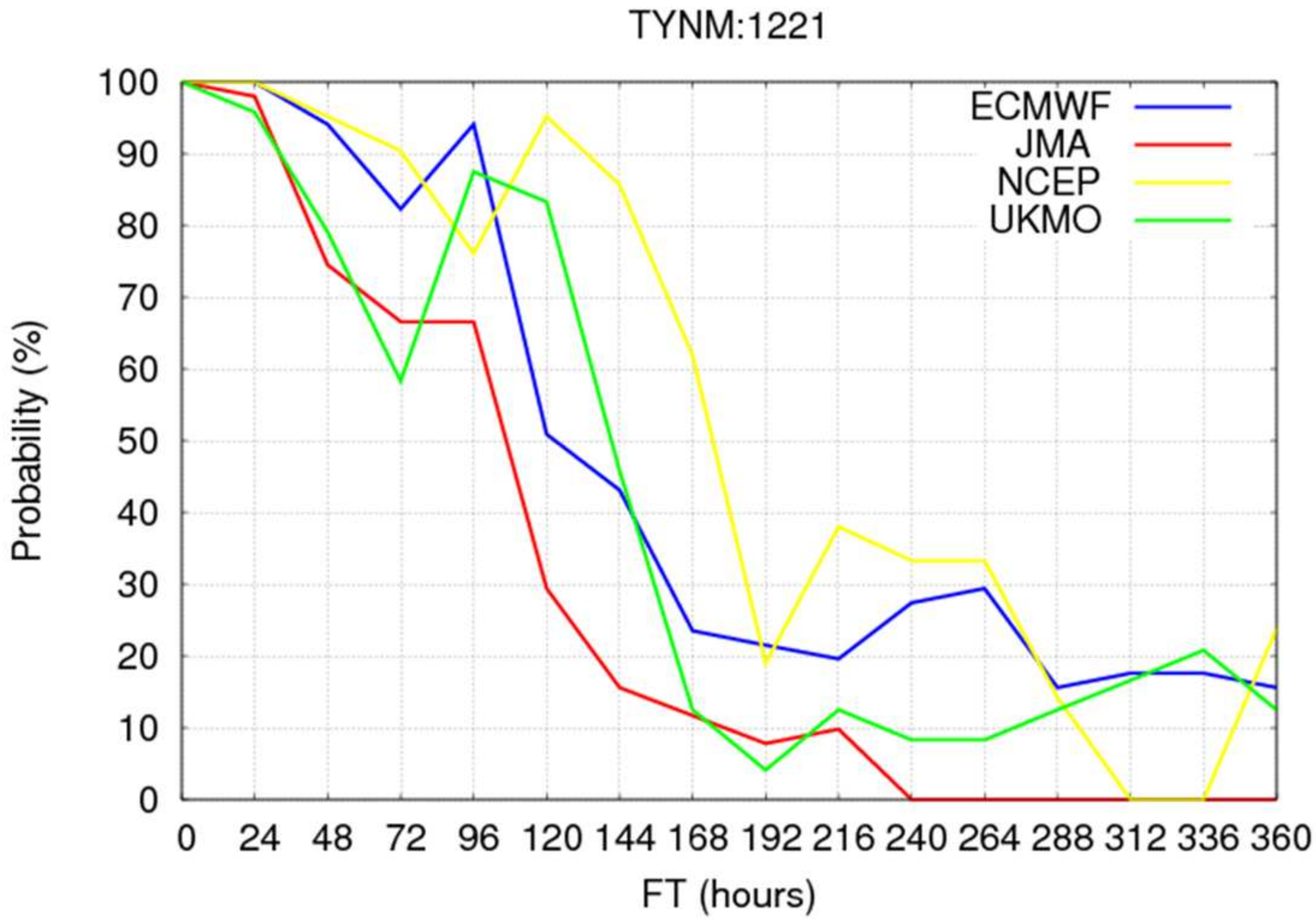



January
February
March
April
May
June
July
August
September
October
November
December


January
February
March
April
May
June
July
August
September
October
November
December

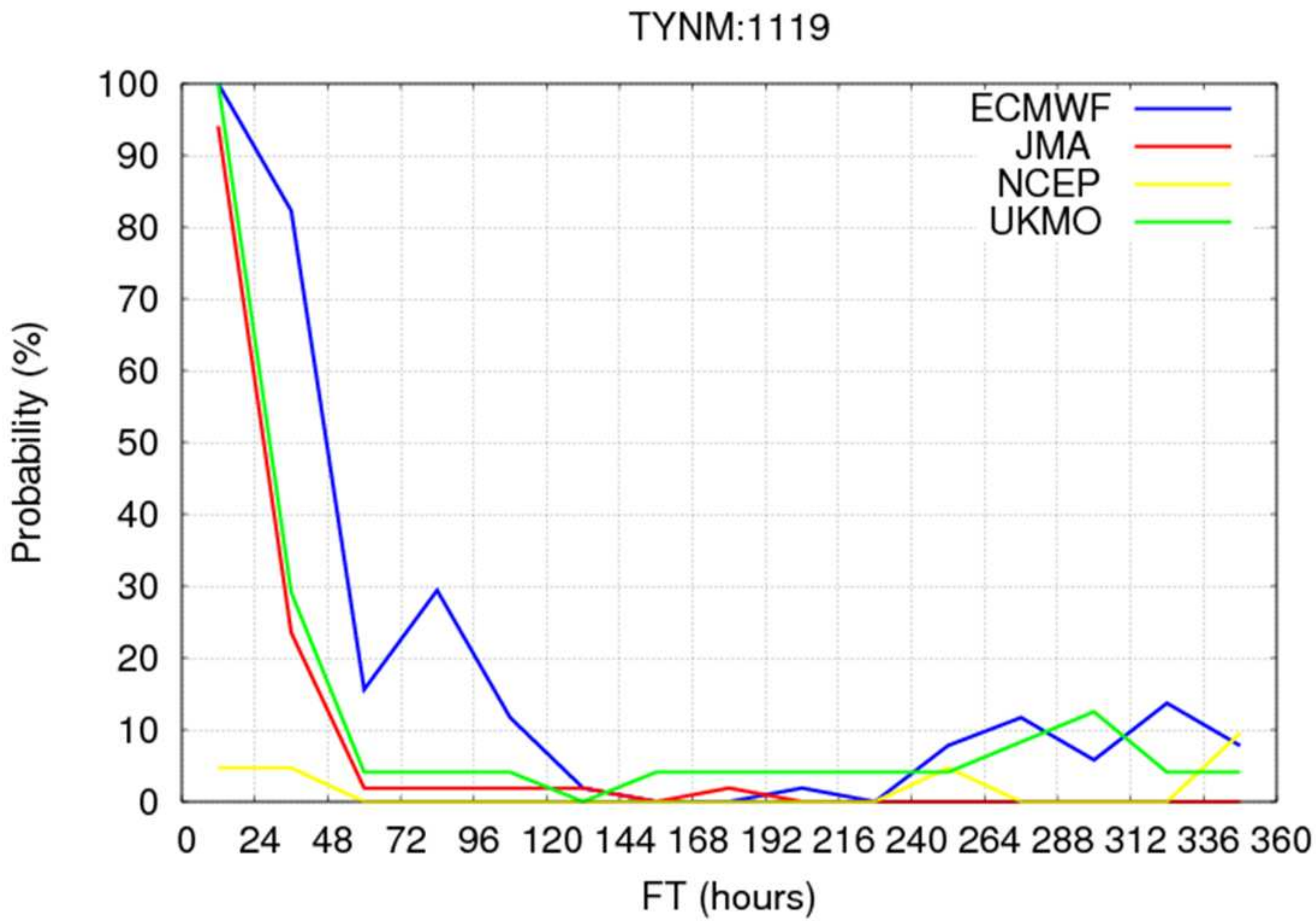
Typhoon PRAPIROON (2012)

All 4 EPSs predict the genesis event 5 days ahead with a probability of 30 % or more.



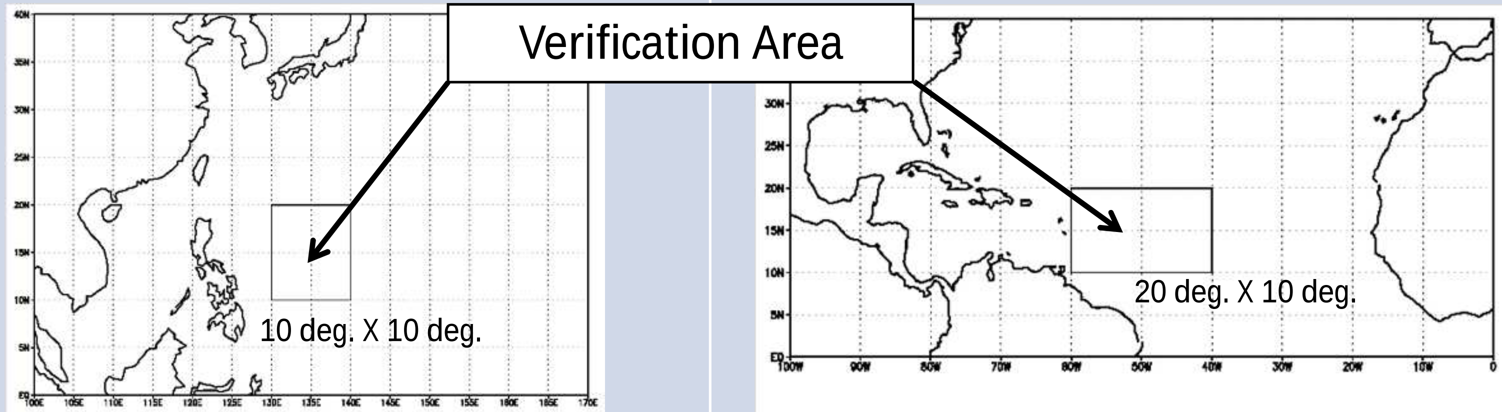
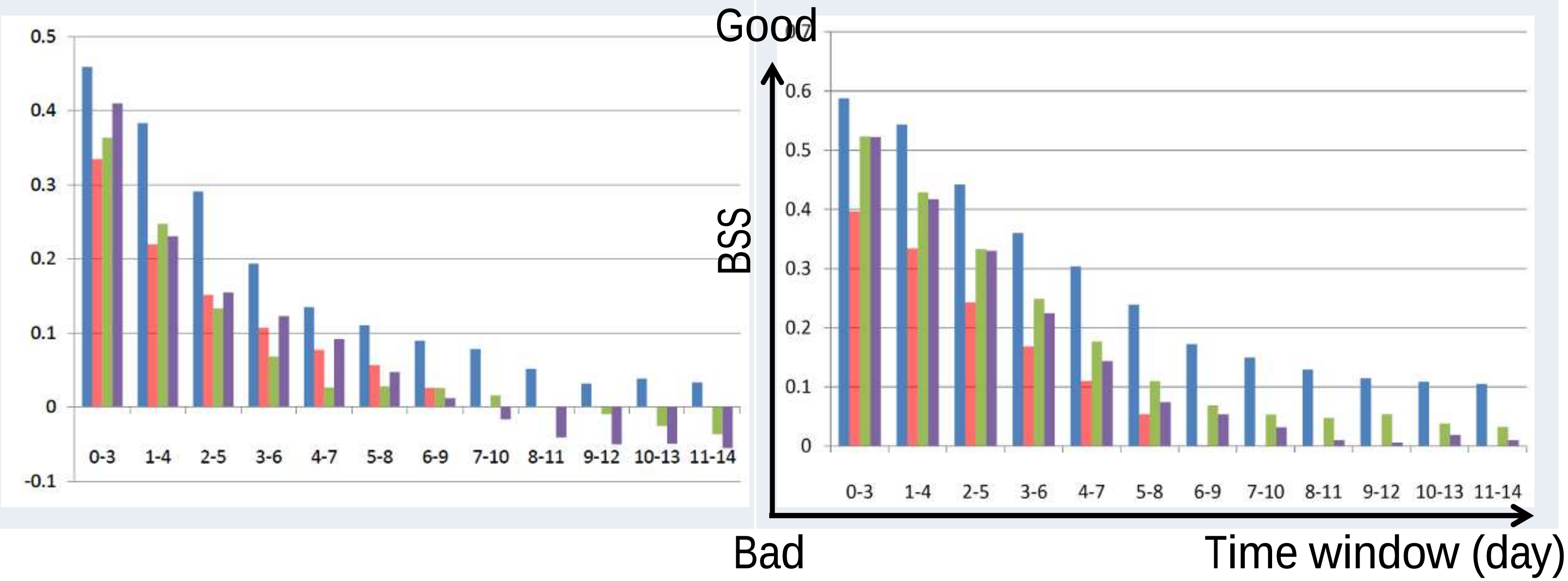
Typhoon NALGAE (2011)

There are several cases where all 4 EPSs have less predictability.

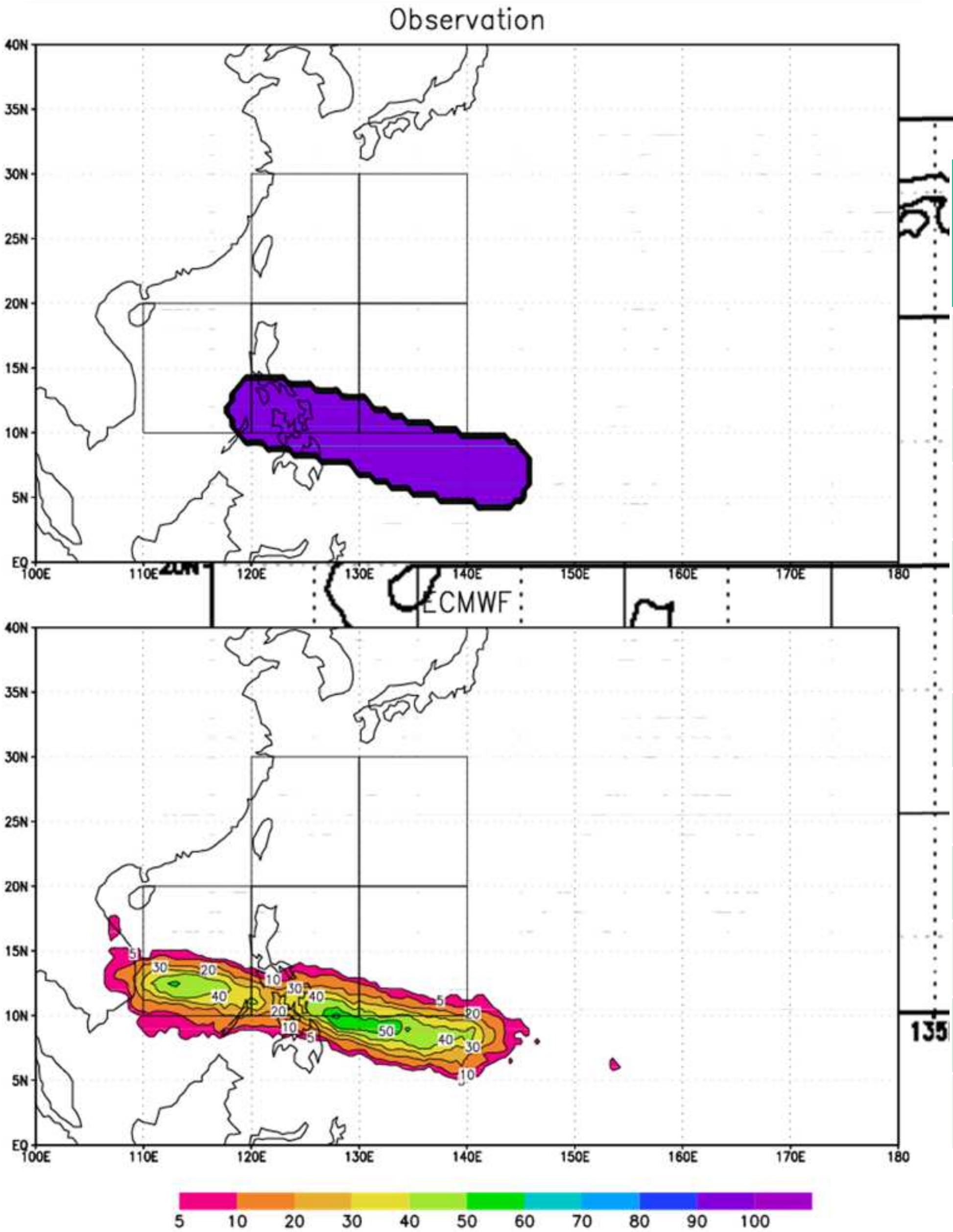


Verification of Tropical Cyclone Activity Prediction

Blue: ECMW, **Red**: JMA, **Green**: NCEP, **Purple**: UKMO

	Western North Pacific	North Atlantic
Verif. Area		
BSS		

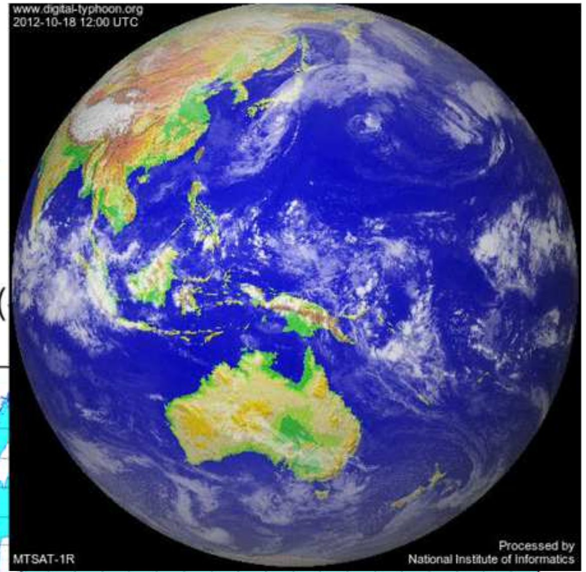
Verification box



Probabilistic Contingency Table

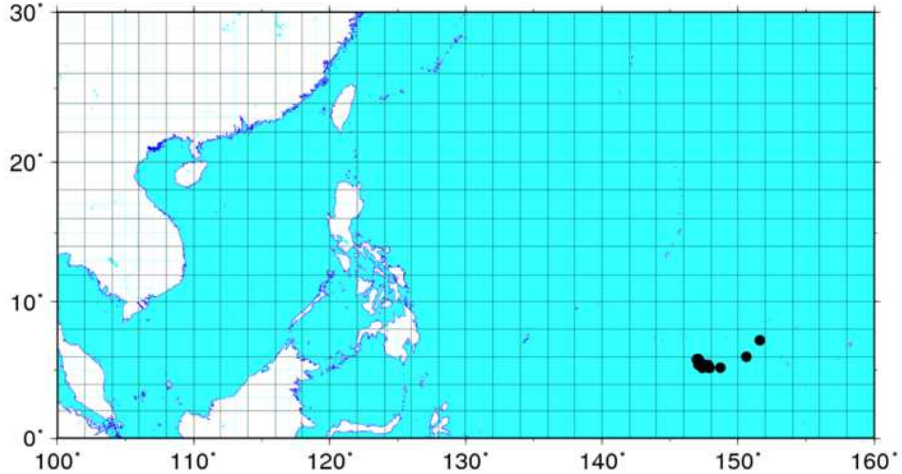
Forecast Probability	Observation	
	Yes	No
0 %	5541	209421
5%	6903	49809
15%	3463	9442
25%	2428	5532
35%	2147	3334
45%	1933	2026
55%	1621	1255
65%	1555	966
75%	1458	667
85%	1511	351
95%	1180	114

Case Study: Typhoon SON-TINH (2012)

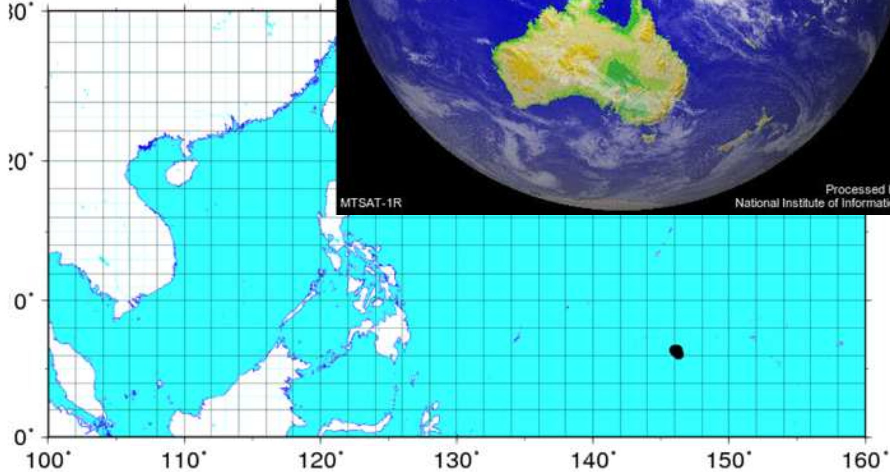


Black dots: detected ensemble storms from all ensemble members

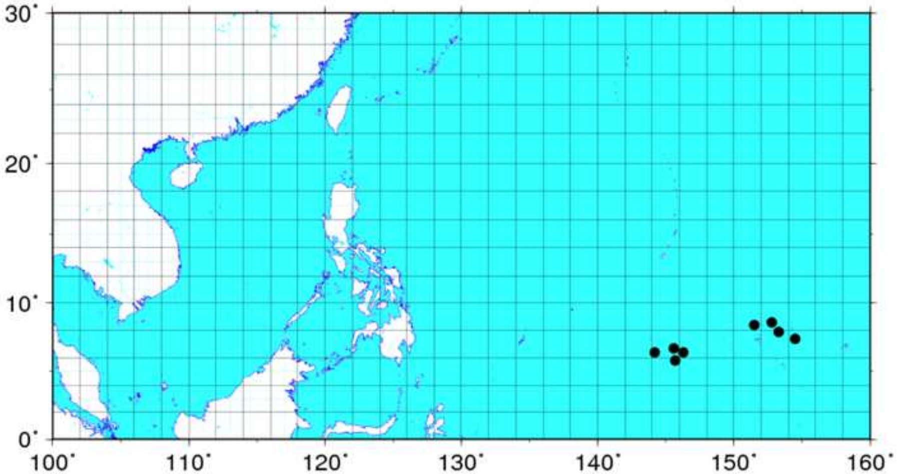
ECMWF FT=0days (–5days relative to genesis date)



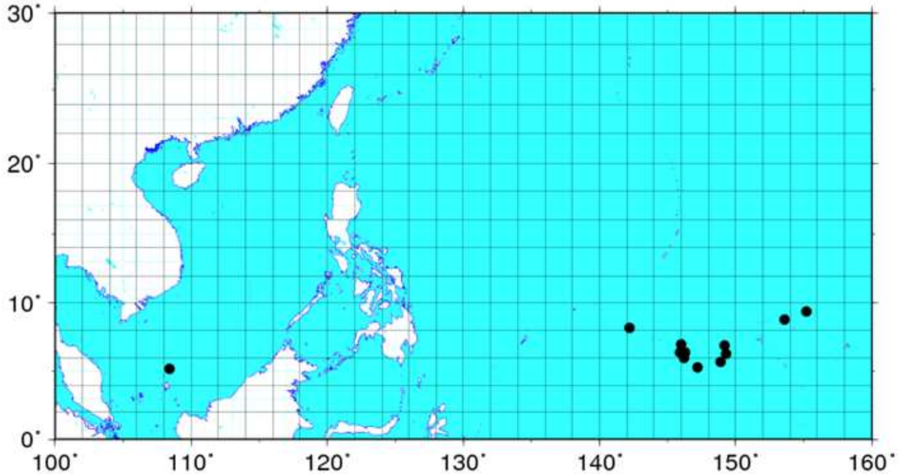
JMA FT=0days (



NCEP FT=0days (–5days relative to genesis date)

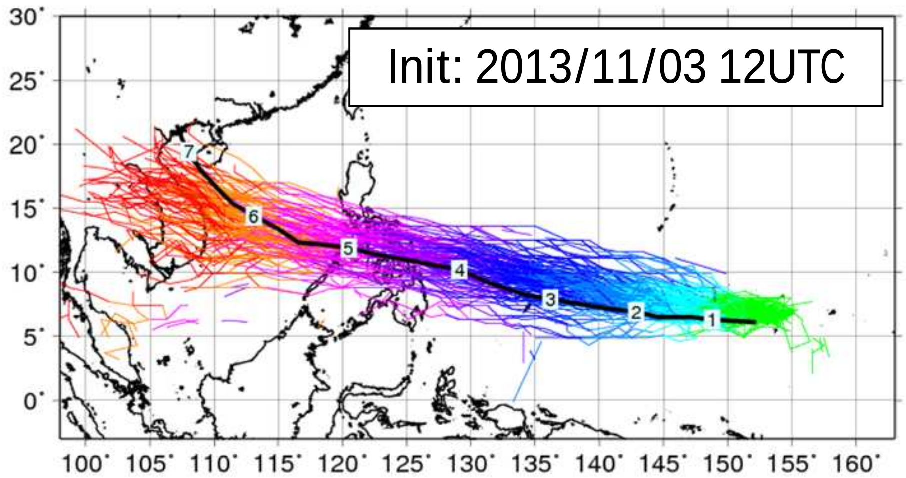


UKMO FT=0days (–5days relative to genesis date)

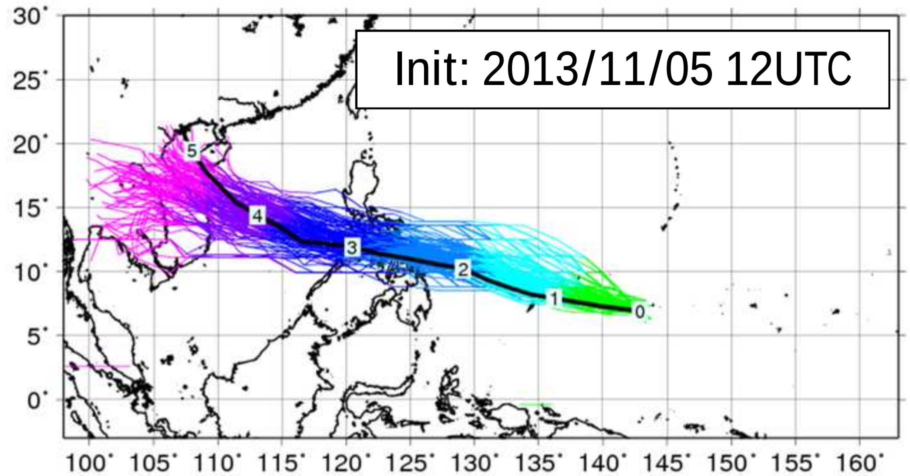


Typhoon Haiyan (2013)

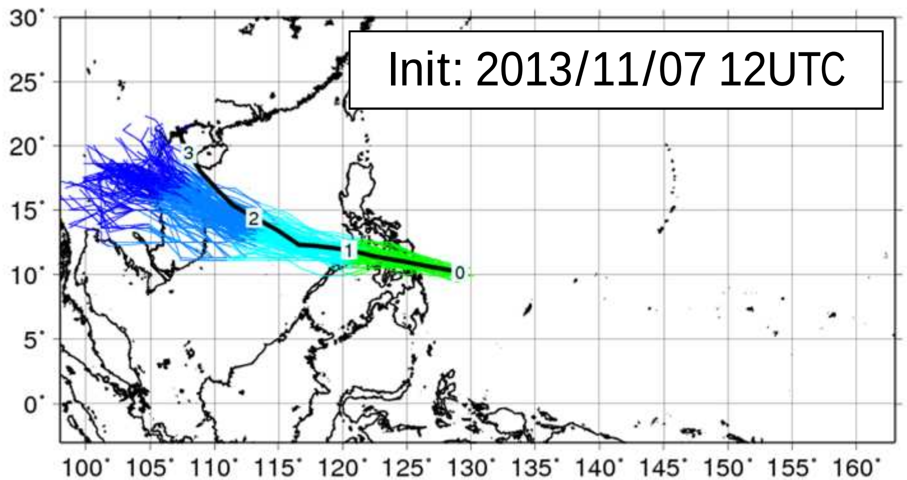
MCGE–4



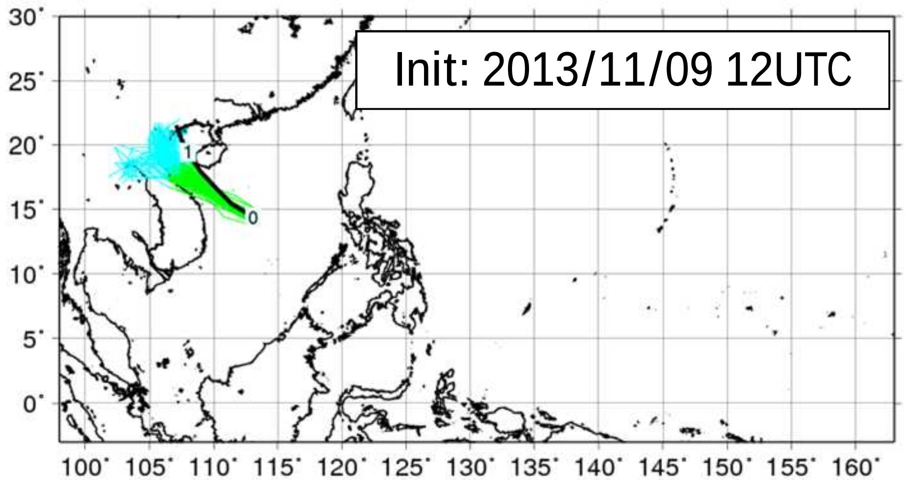
MCGE–4



MCGE–4

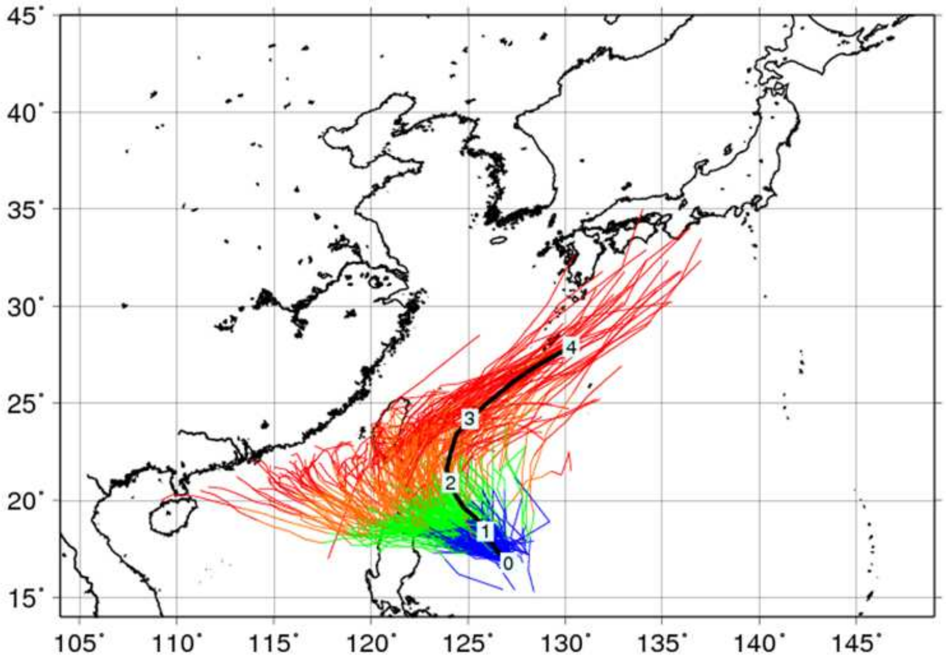


MCGE–4

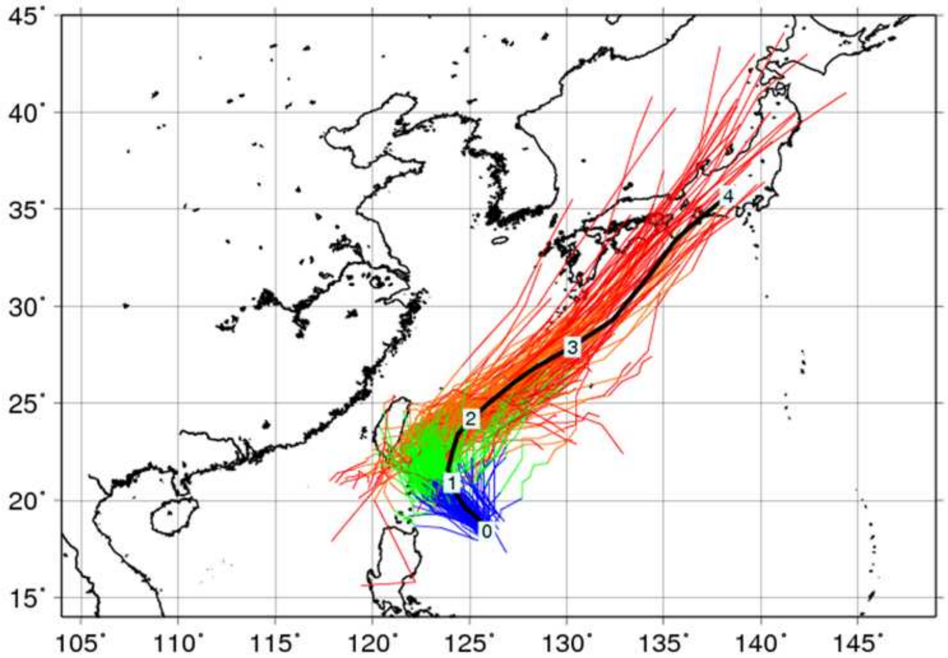


Forecast uncertainty changes day by day

Typhoon Jelawat
Init.: 2012.09.25 12UTC



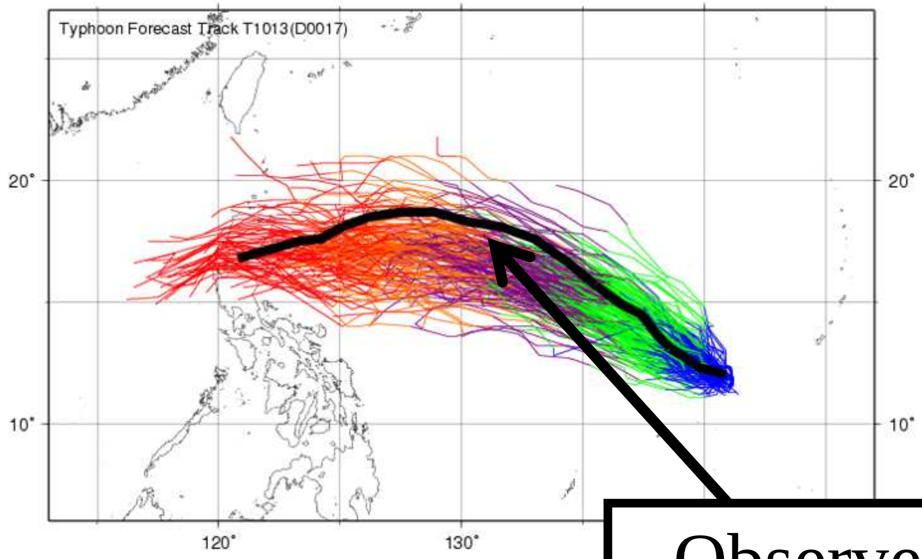
Typhoon Jelawat
Init.: 2012.09.26 12UTC



Typhoon track prediction by MCGE-9 (BOM, CMA, CMC, CPTEC, ECMWF, JMA, KMA, NCEP, UKMO)

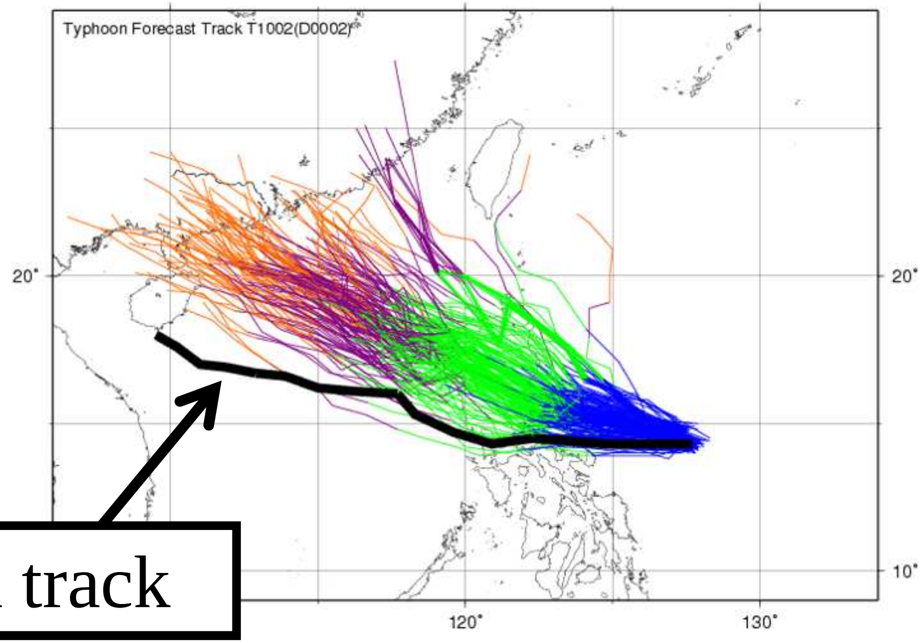
Good example

Typhoon **Megi** initiated at
1200 UTC 25th Oct. 2010



Bad example

Typhoon **Conson** initiated at
1200 UTC 12th Jul. 2010



Observed track

There are prediction cases where any SMEs cannot capture the observed track.
=> It would be of great importance to identify the cause of these events and modify the NWP systems including the EPSs for better probabilistic forecasts.