Ensemble Tropical Cyclone Activity Prediction using TIGGE data

8th Integrated Workshop (8th IWS)/
2nd Training and Research Coordination
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3: U.S. Naval Postgraduate School
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 TC track predictions for Hurricane Sandy, Cyclone Phailin, and Typhoon Haiyan

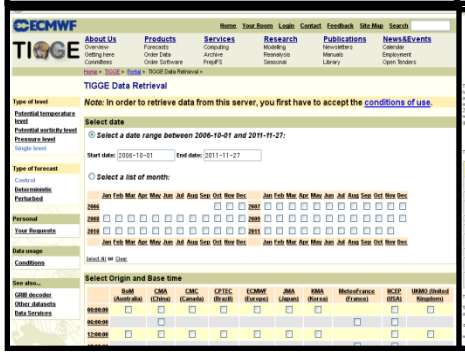
4. **Summary**

What is TIGGE?

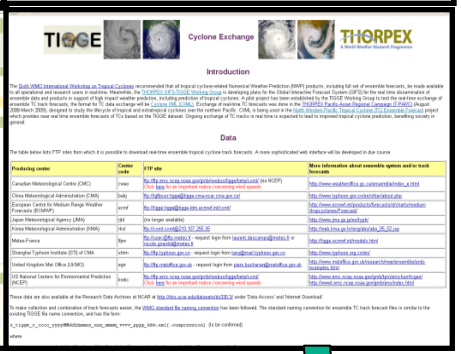
Past

Research Phase

TIGGE
(started 2006)

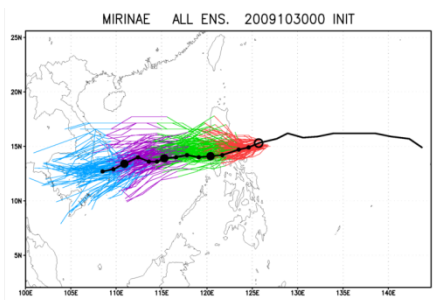


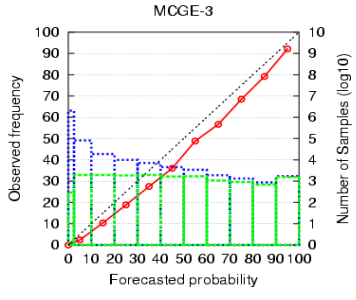
Cyclone XML
(started 2008)



Future

Operational Phase





Goal: Enhanced use of ensemble prediction for operational purposes

Present

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

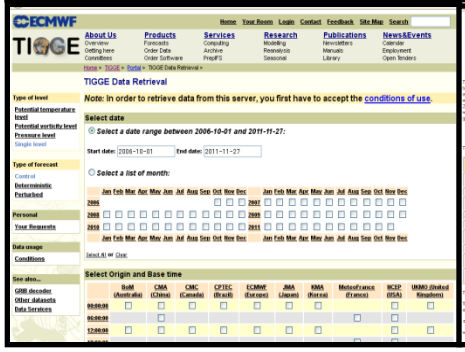
- North Western Pacific Tropical Cyclone (TC) Ensemble Forecast Project **(NWP-TCEFP)**
- Severe Weather Forecasting Demonstration Project **(SWFDP)**

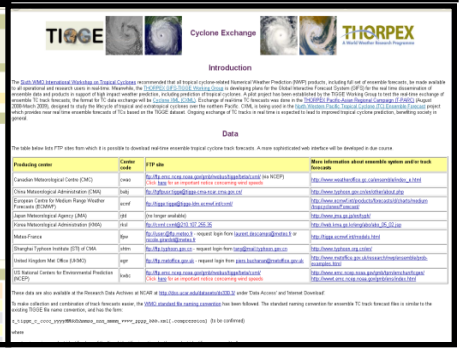
What is the benefit of using TIGGE?

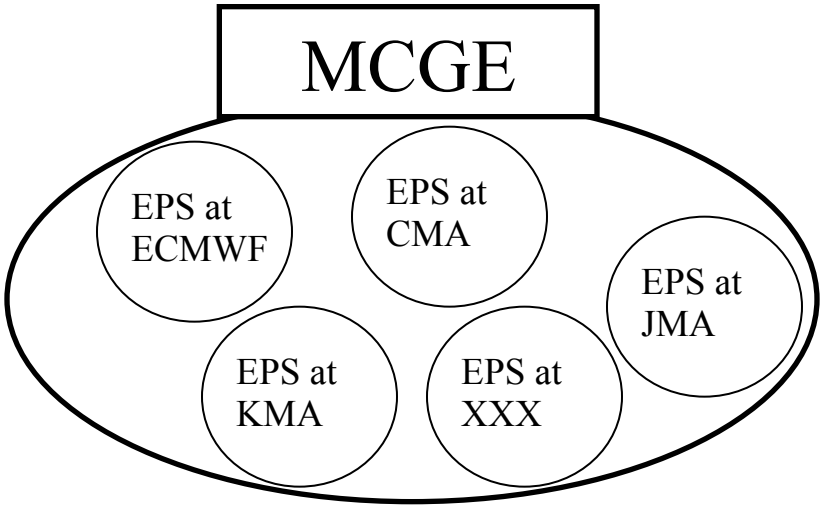
Past

Research Phase

TIGGE (started 2006)	Cyclone XML (started 2008)





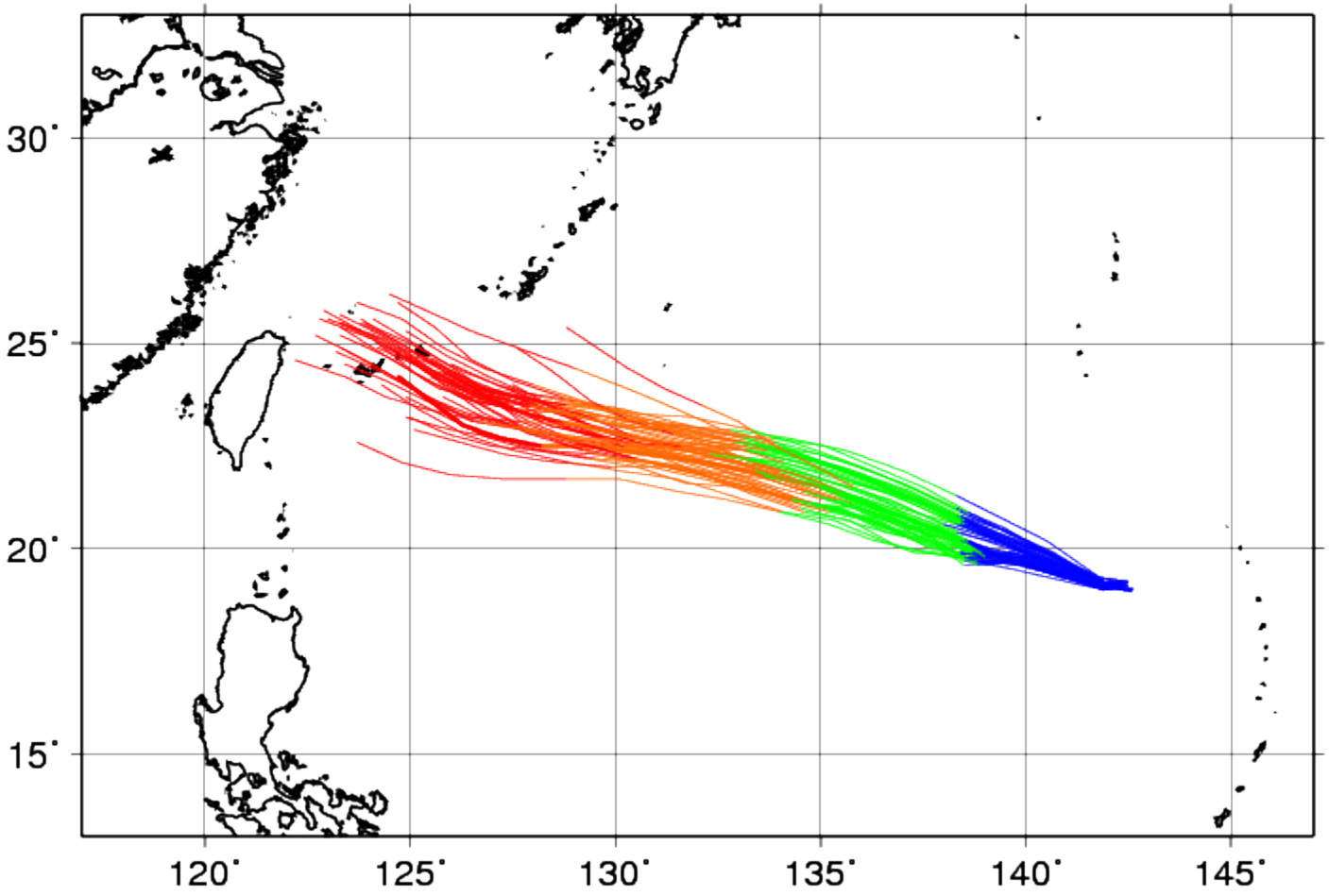


MCGE is an ensemble of ensembles of major NWP centers.

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

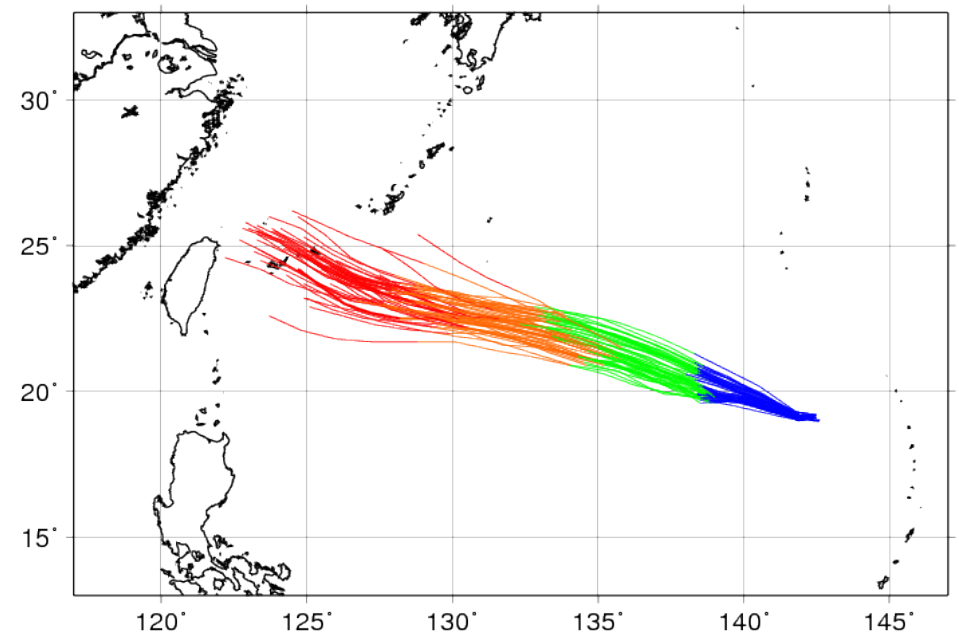
Track Prediction for Typhoon SOULIK (2013)

JMA



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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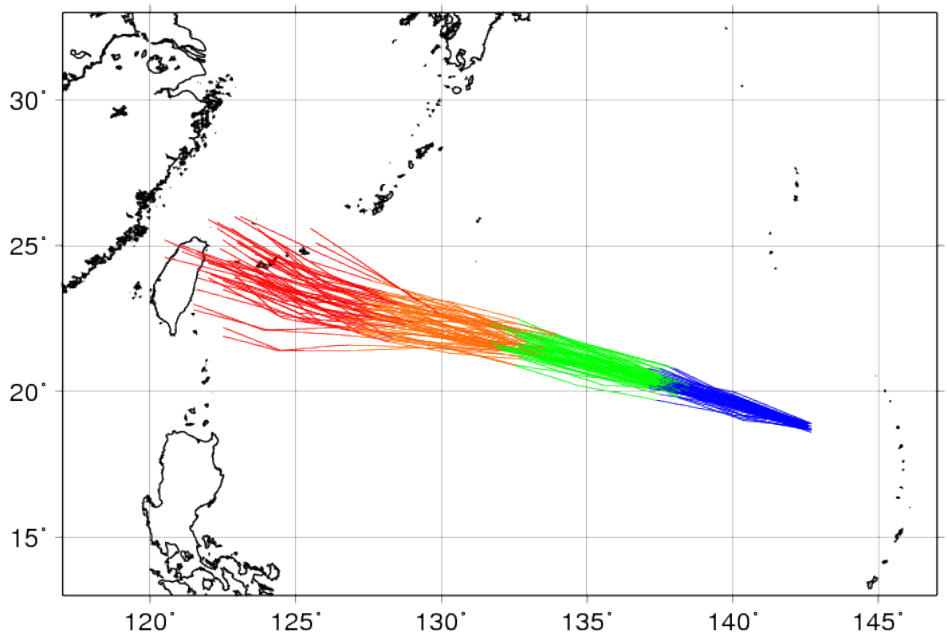
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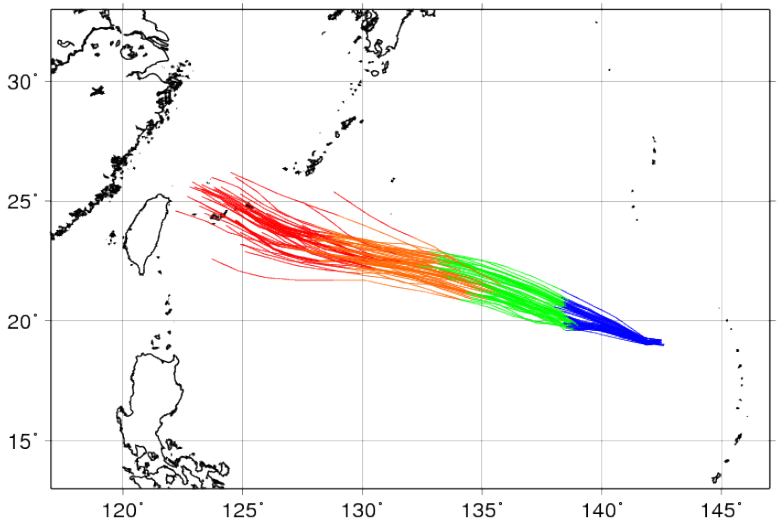

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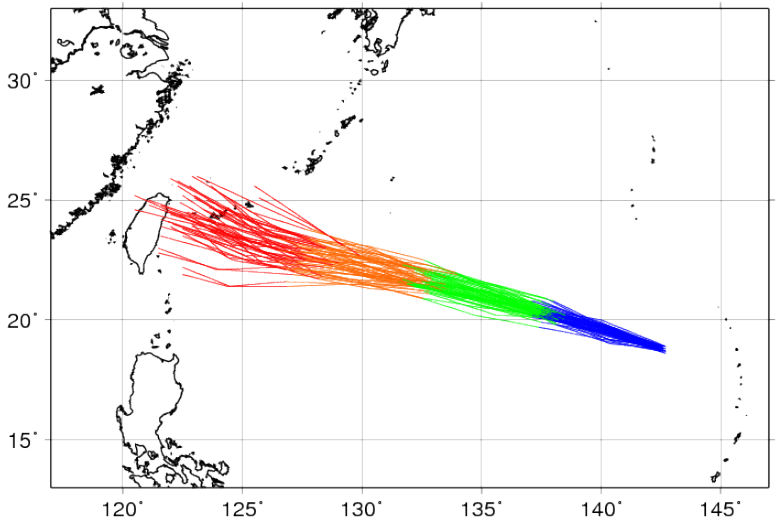

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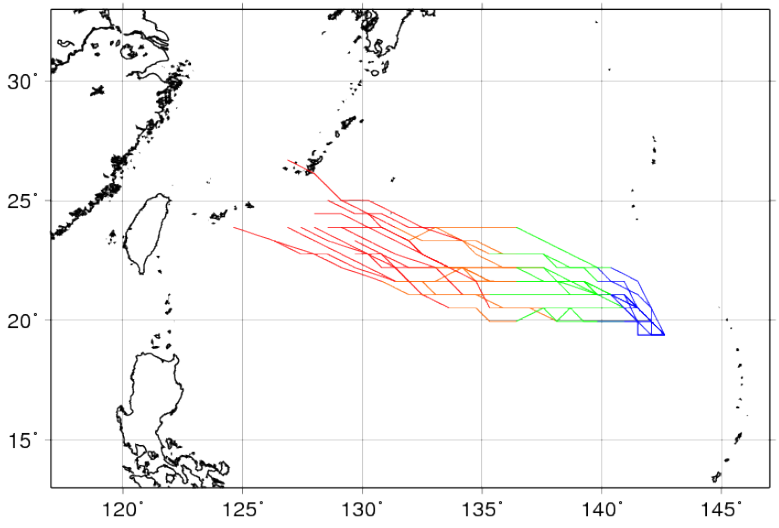

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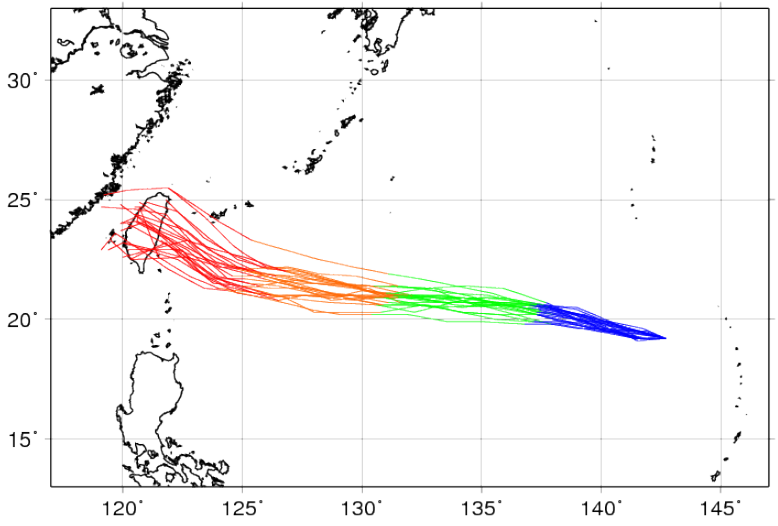

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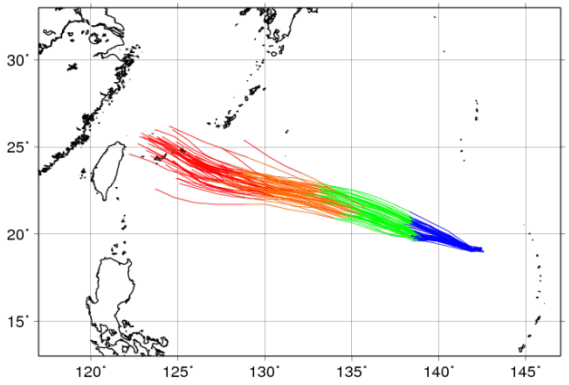

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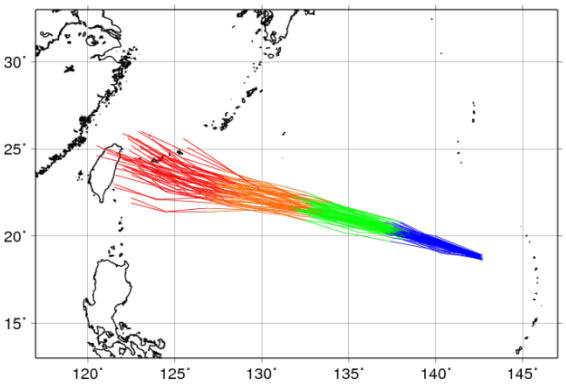

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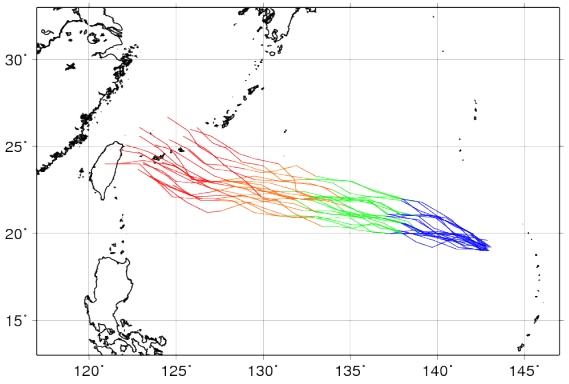

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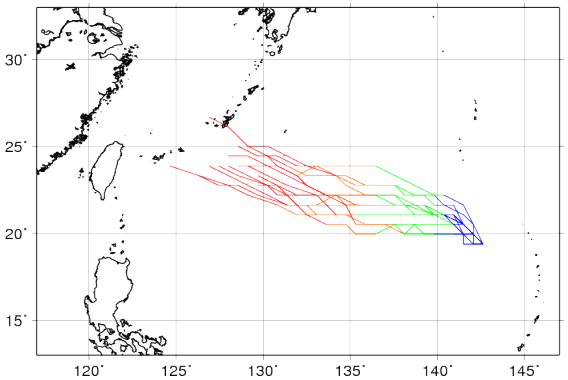

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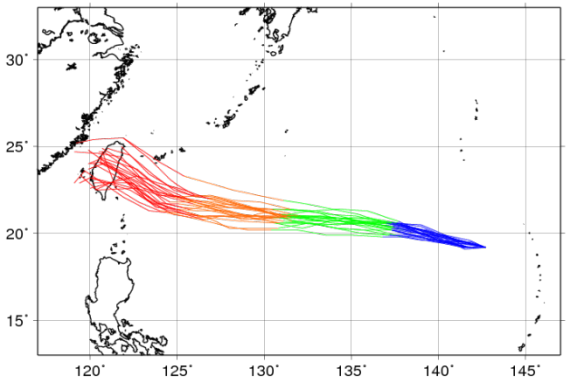

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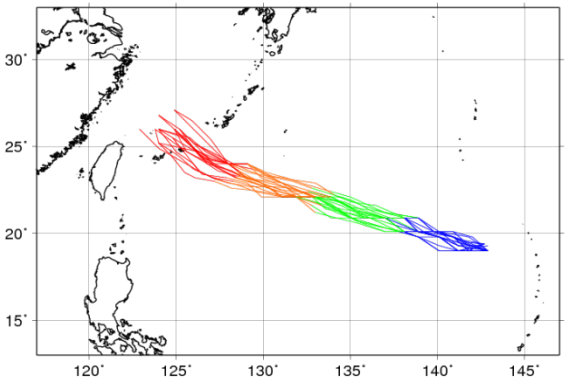
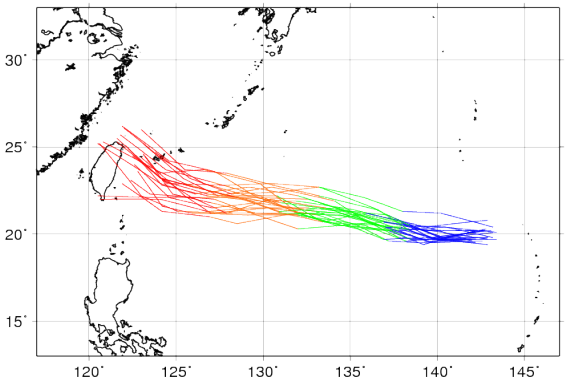


UKMO



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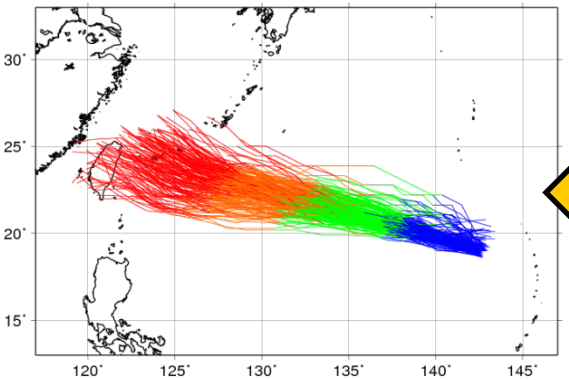

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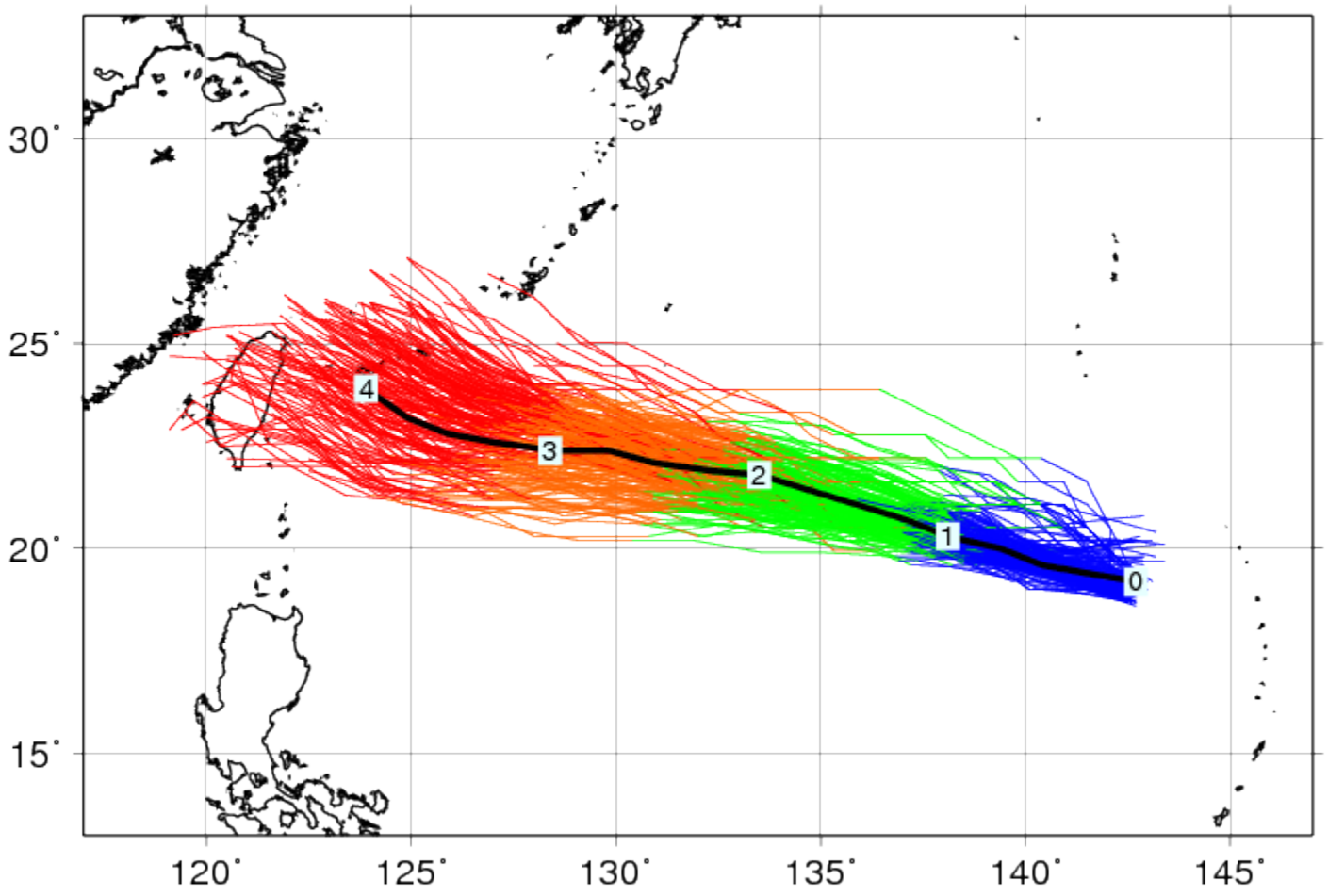
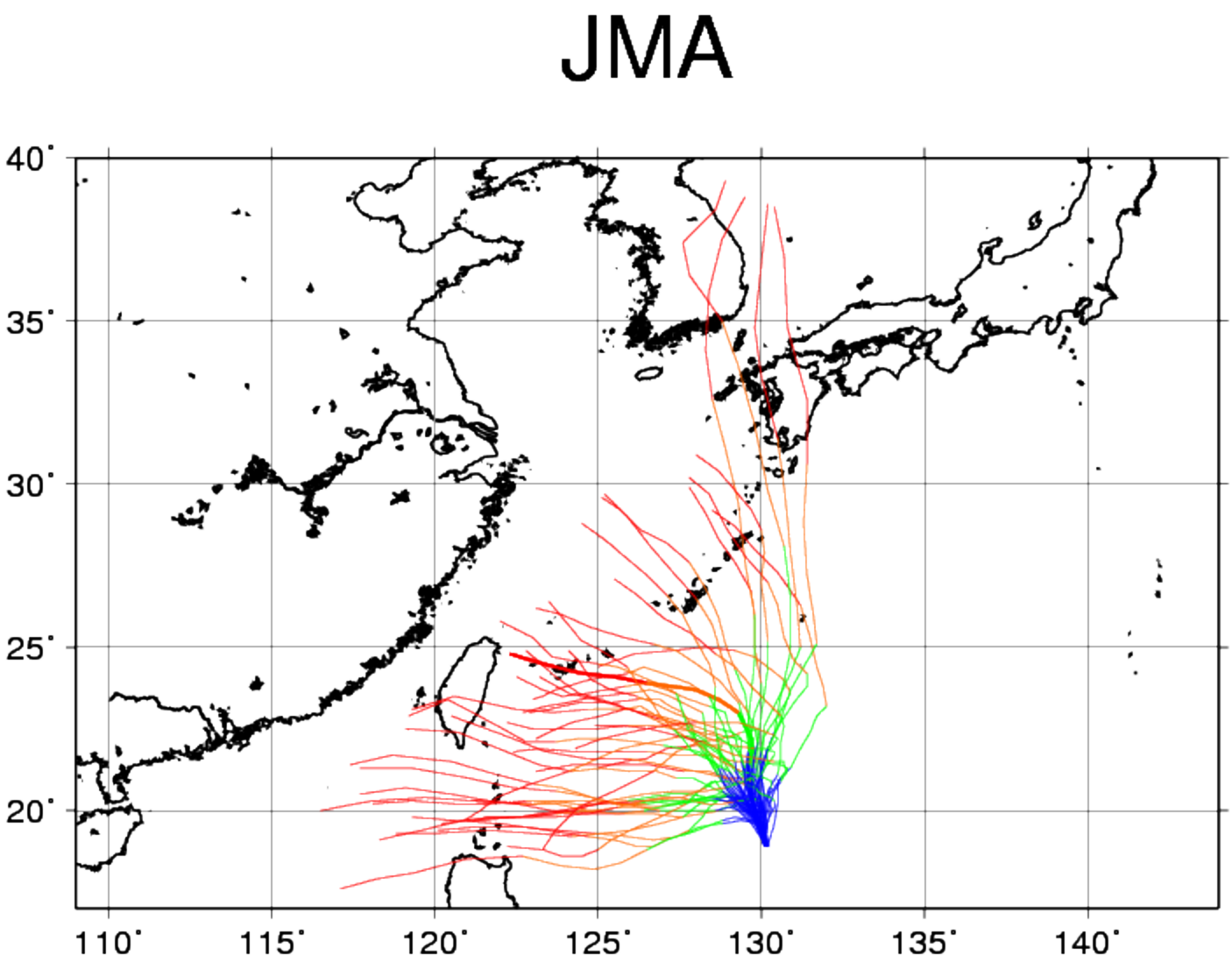
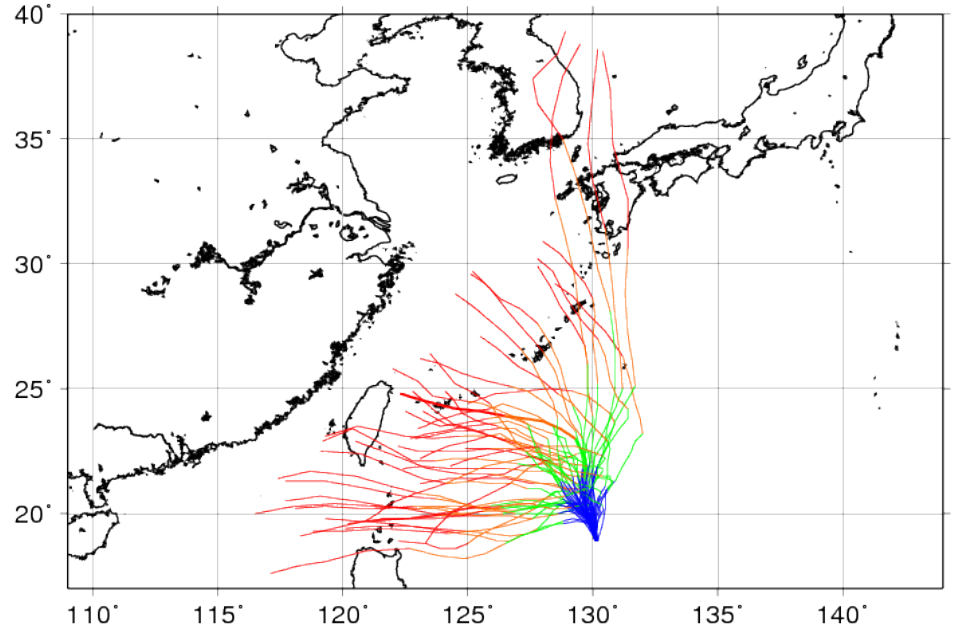


Black line is the observed track.
The number on the black line indicates day(s) from the initial date.

Track Prediction for Typhoon FITOW (2013)



JMA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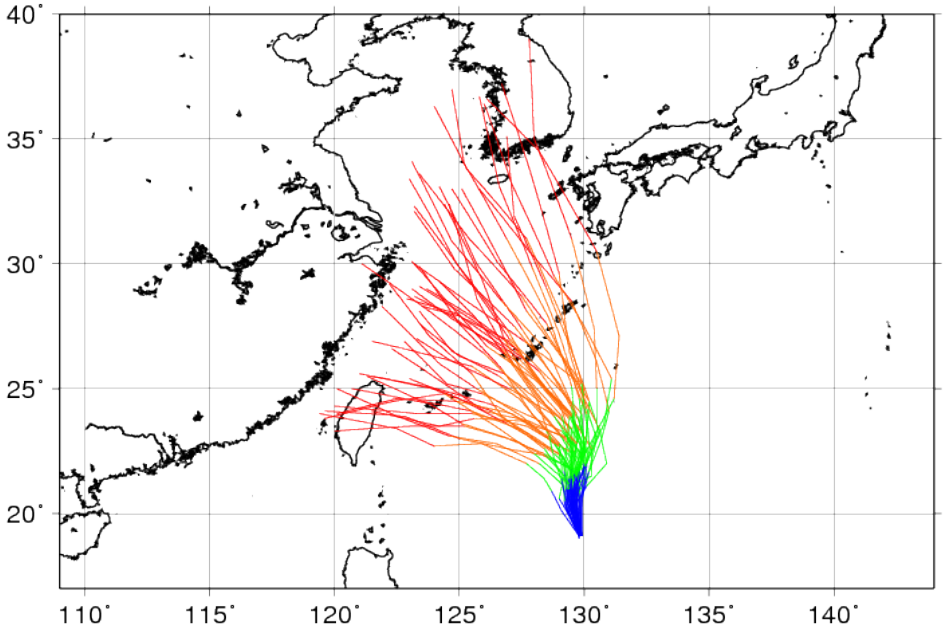
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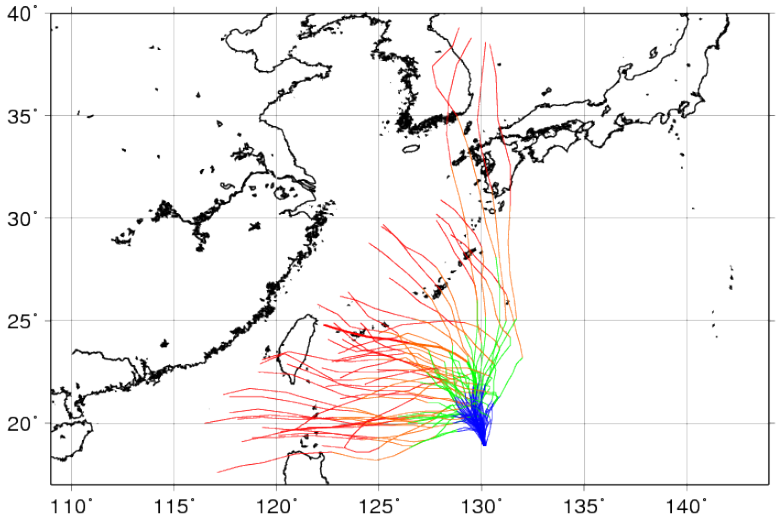

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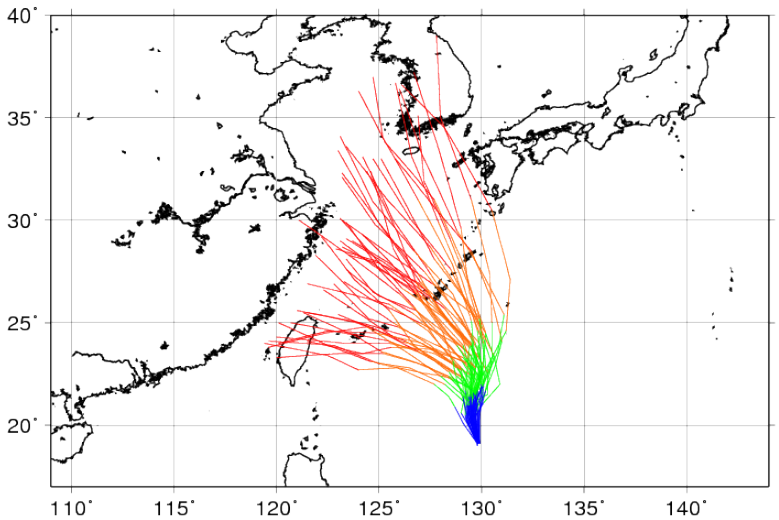

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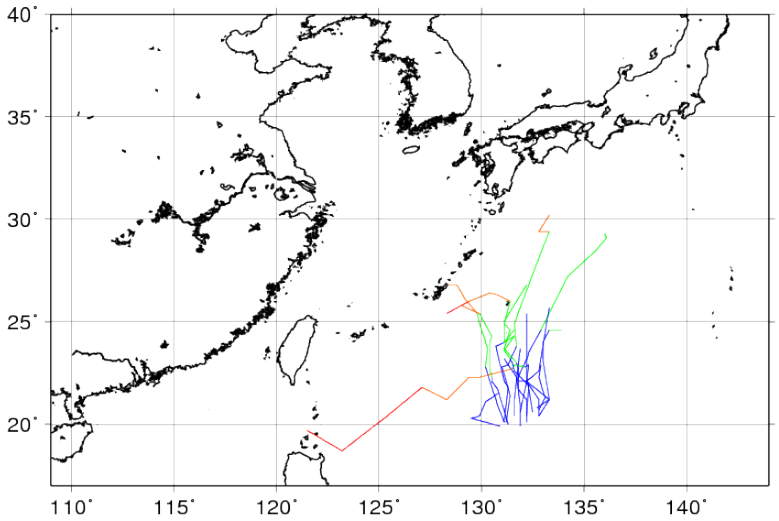

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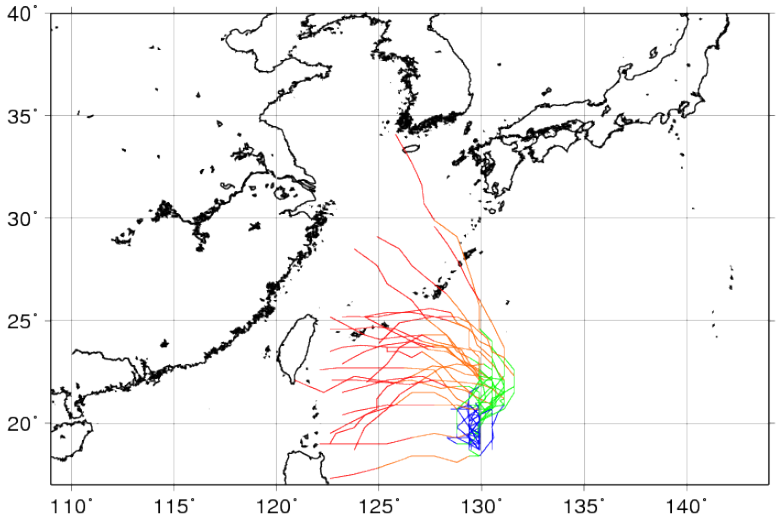

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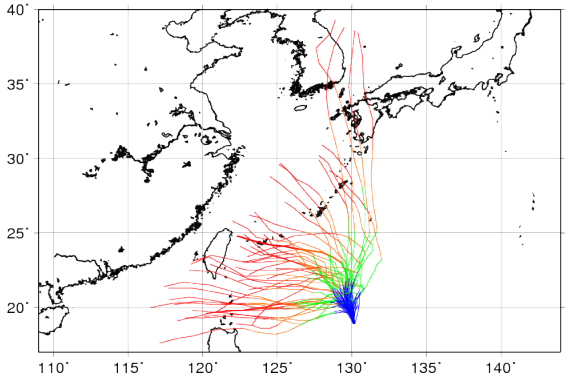

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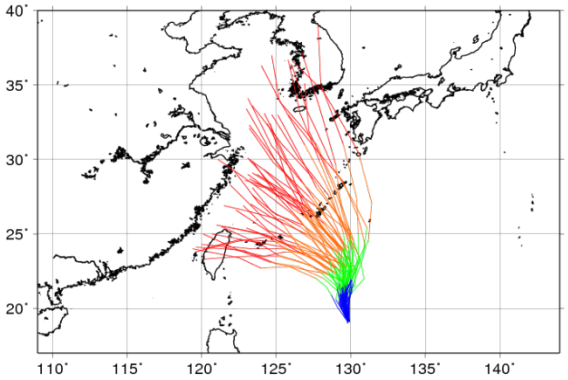

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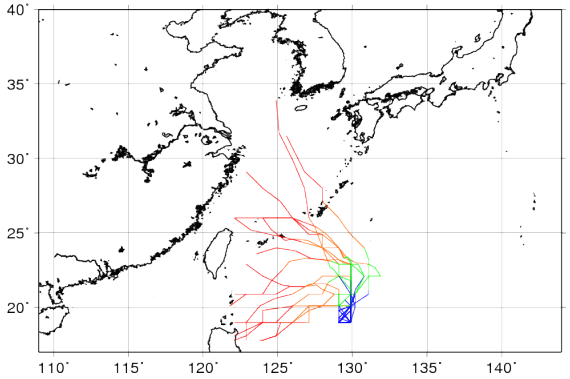

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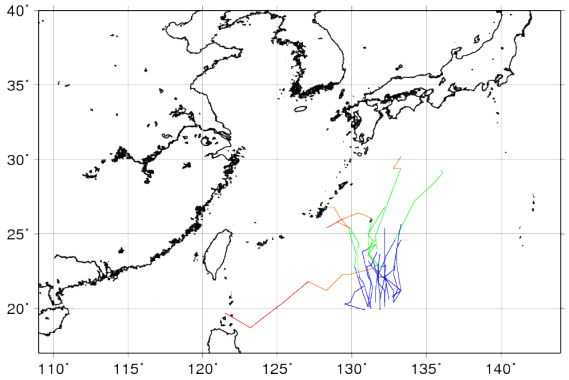

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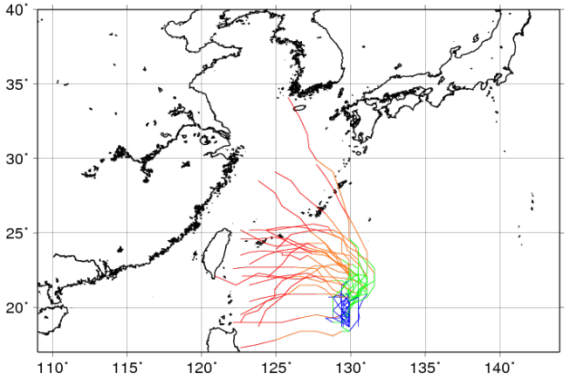

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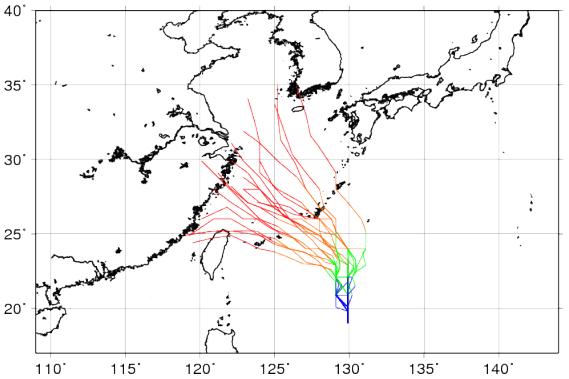

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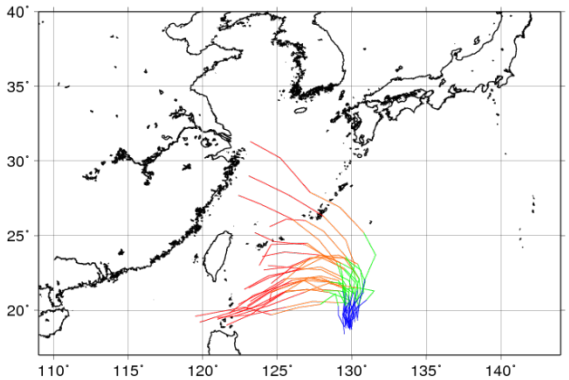
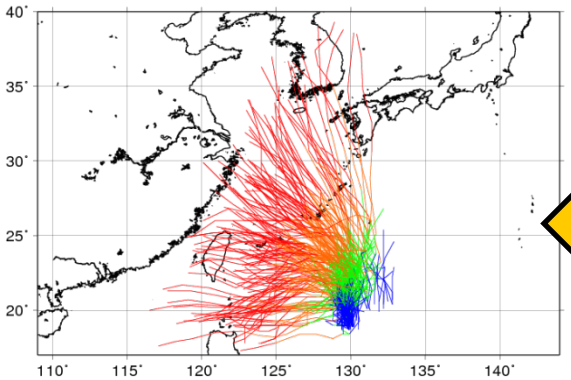


MCGE



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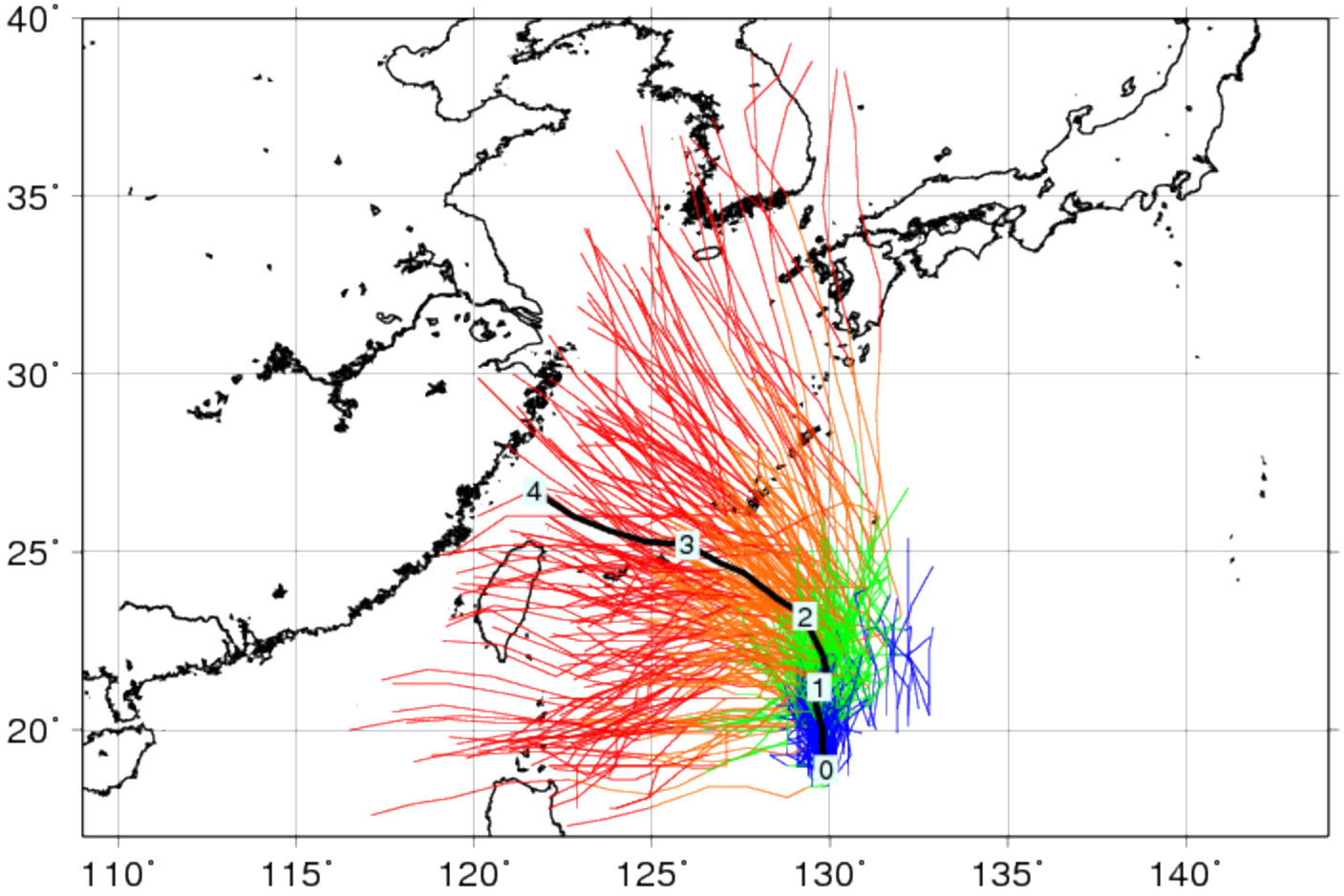
MCGE



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
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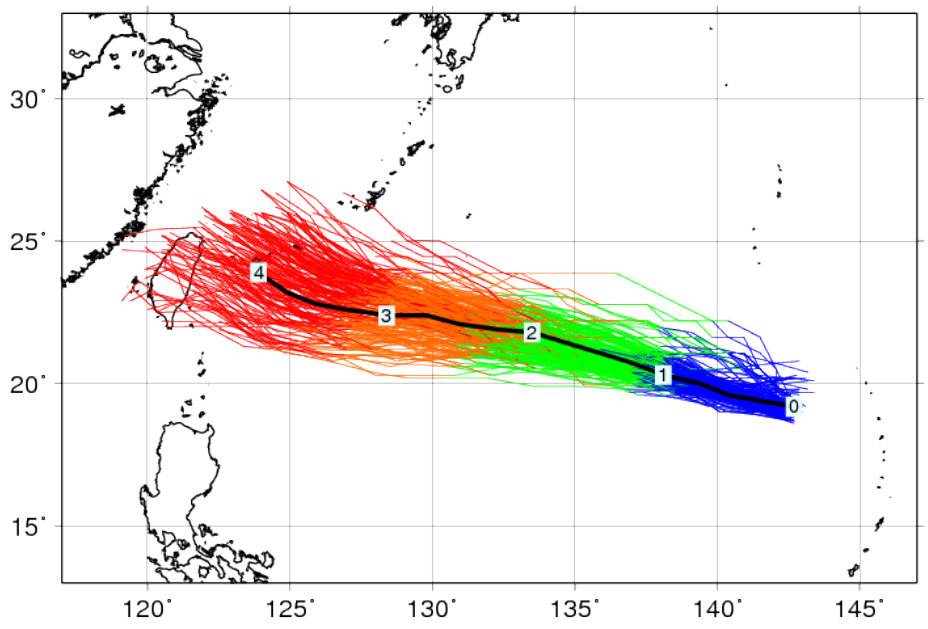

Typhoon FITOW
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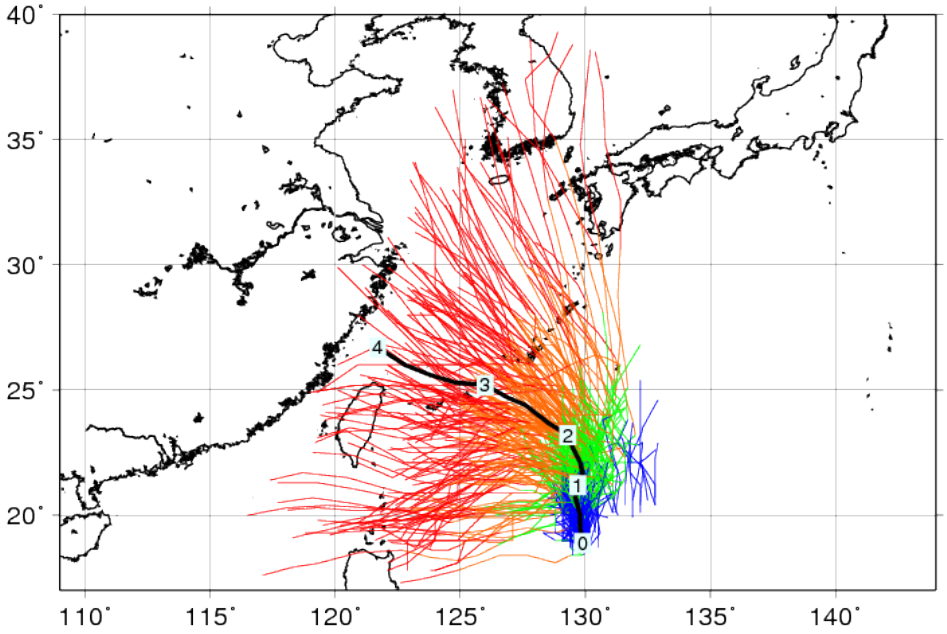


MCGE products provide forecasters with additional information on the forecast uncertainty and increase the level of confidence in the forecast.

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

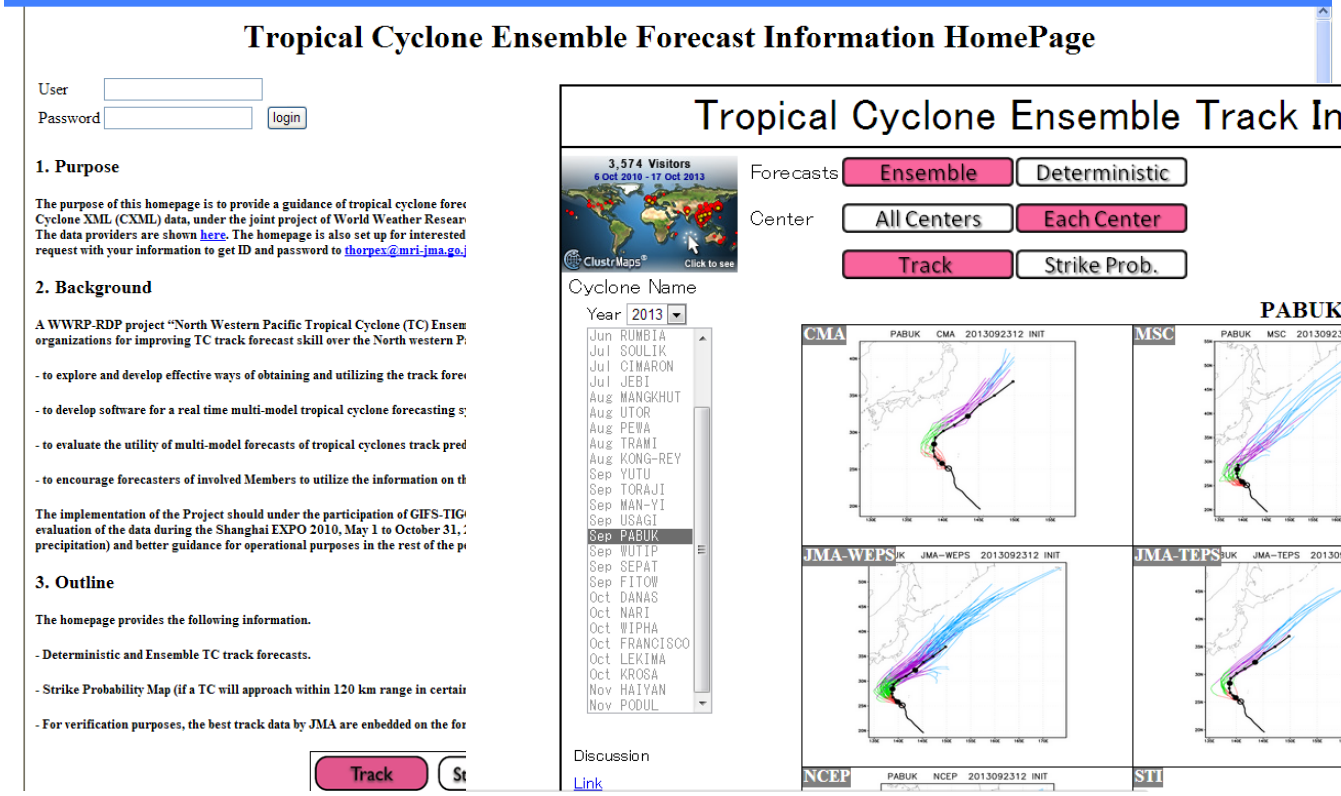
The position errors of 5-day predictions by the MCGE-3 are slightly smaller than that of the ensemble mean of the best SME although the difference is not statistically significant.

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)

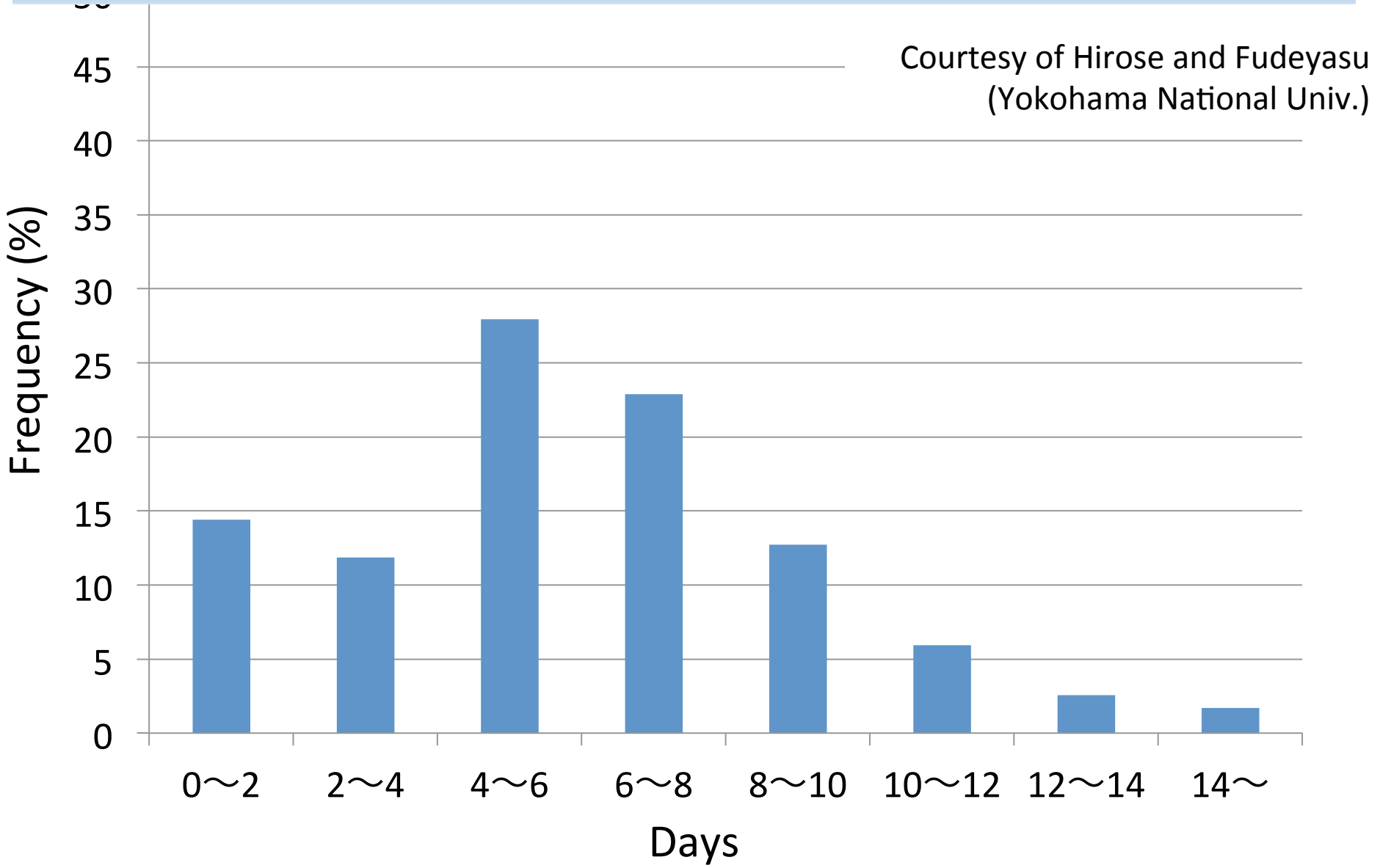


Send e-mail to thorpex@mri-jma.go.jp to get ID and password

Ensemble tropical cyclone activity prediction

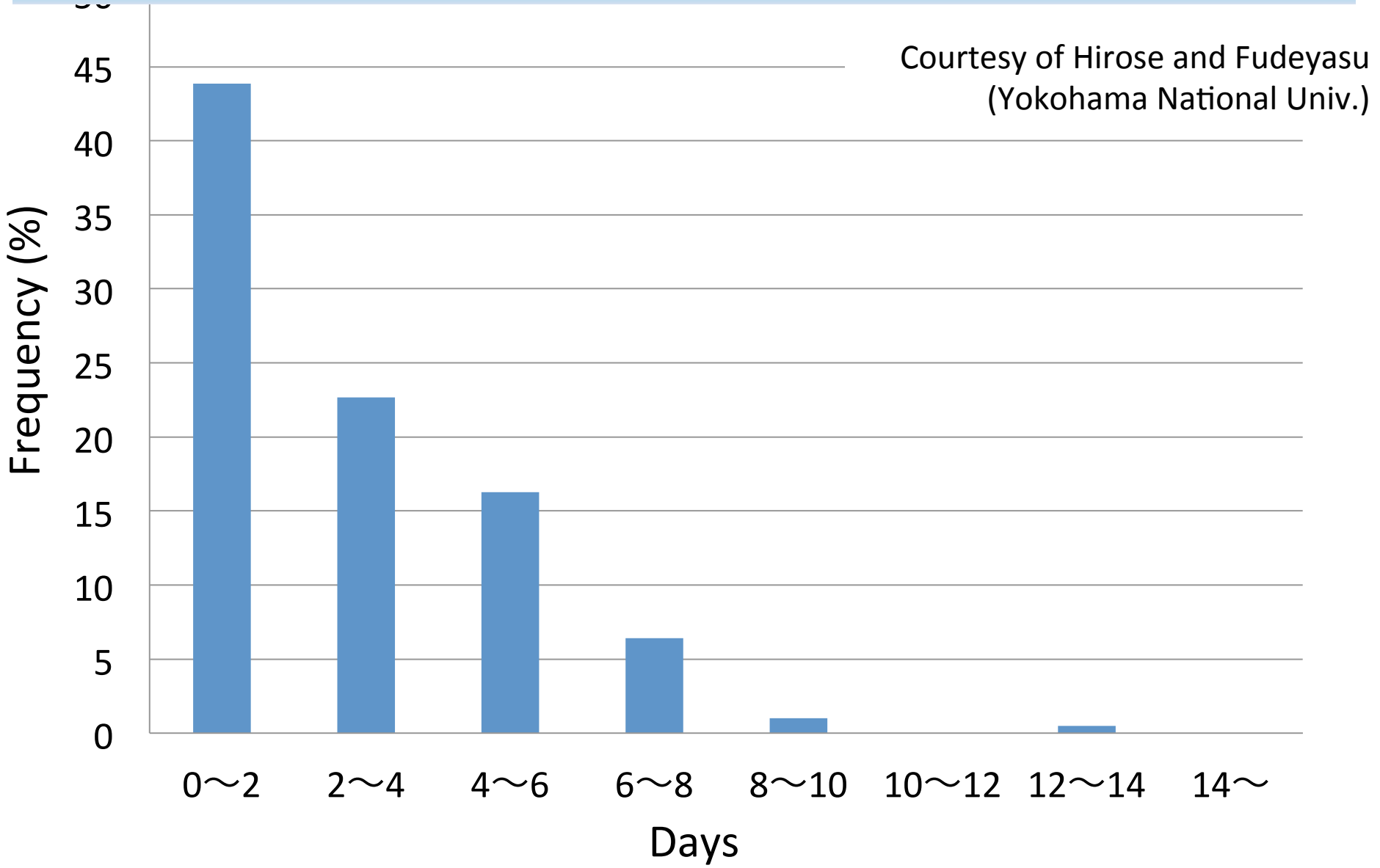
Frequency of days from TC genesis to the landfall

-Japan-



Frequency of days from TC genesis to the landfall

-Philippines-



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

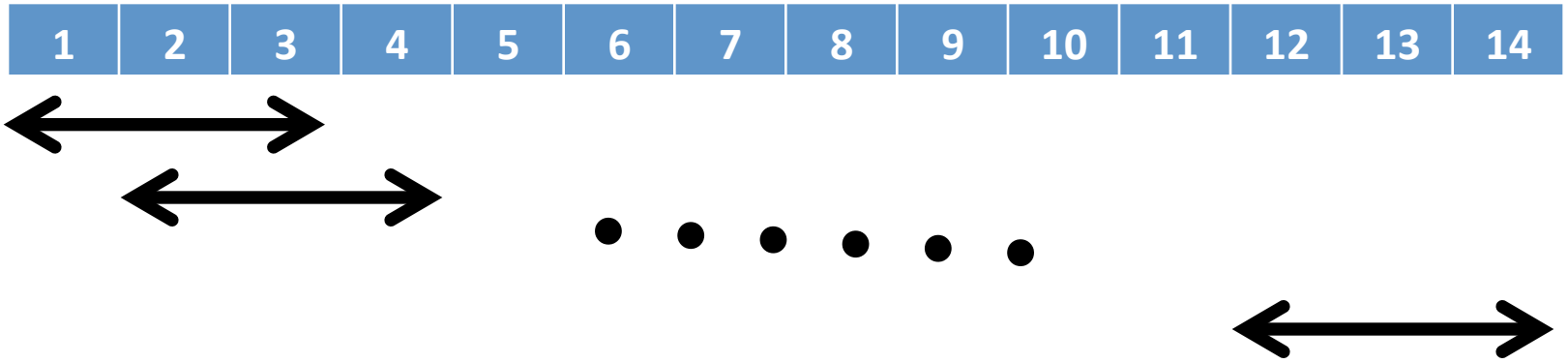
This study is one of the annual operating plans (AOPs) of the Working Group on Meteorology (WGM) for 2013.

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**).

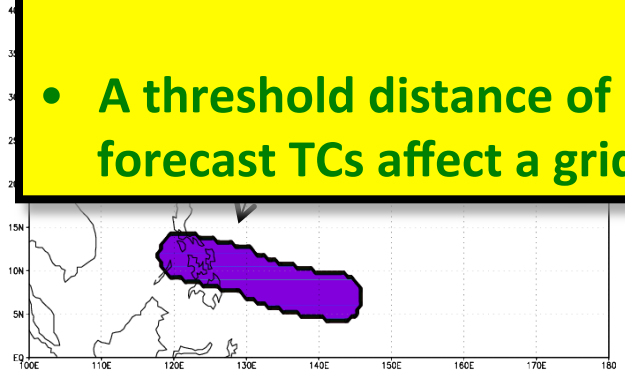
- Verify ensemble predictions of TC activity within **a 3 day time window**, which is applied over a forecast length of **2 weeks**.

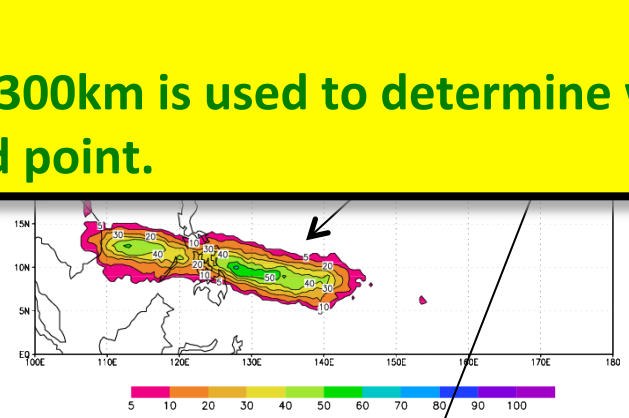


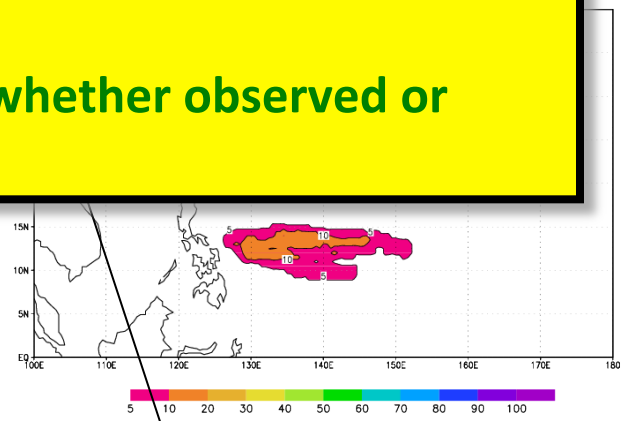
Example: TC activity probability maps -Haiyan-

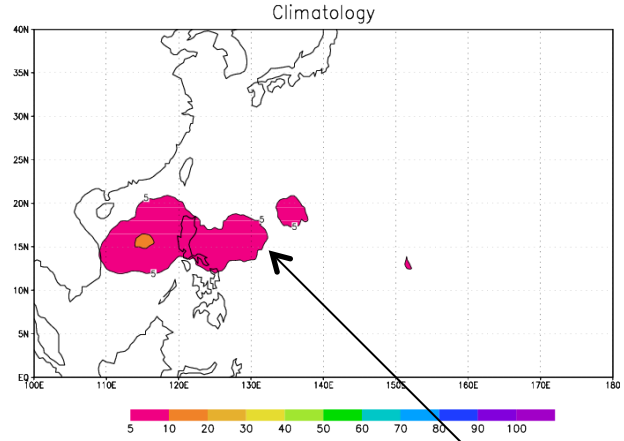
- Initial time of the forecasts: 2013/10/31 12 UTC (about **4 days before the genesis** and **8 days before the landfall** over the Philippines)
- Time window: 2013/11/05 12 UTC – 2013/11/08 12 UTC (T+5days – T+8days)

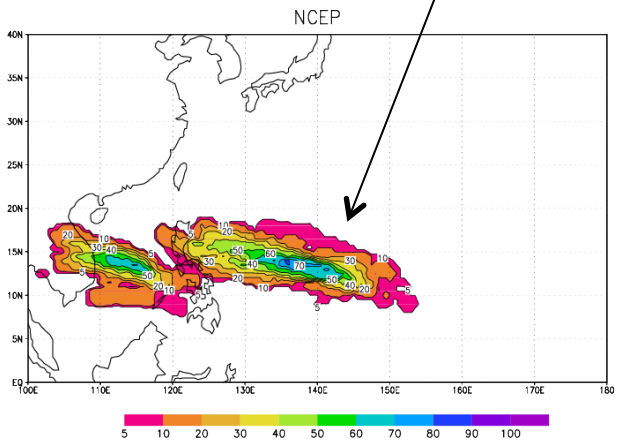
- **Probabilities are calculated at each grid point of a 0.5 x 0.5 deg. grid space**
- **A threshold distance of 300km is used to determine whether observed or forecast TCs affect a grid point.**

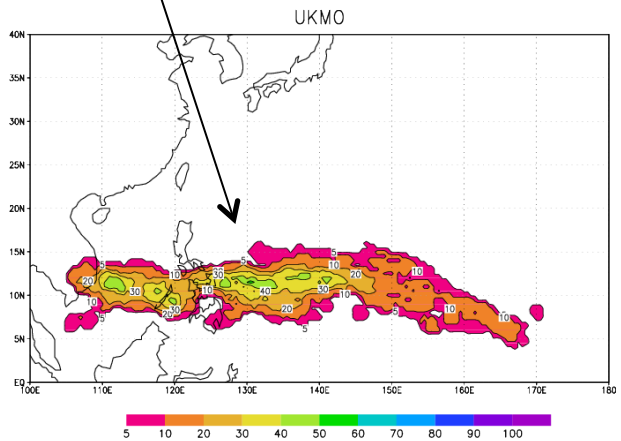






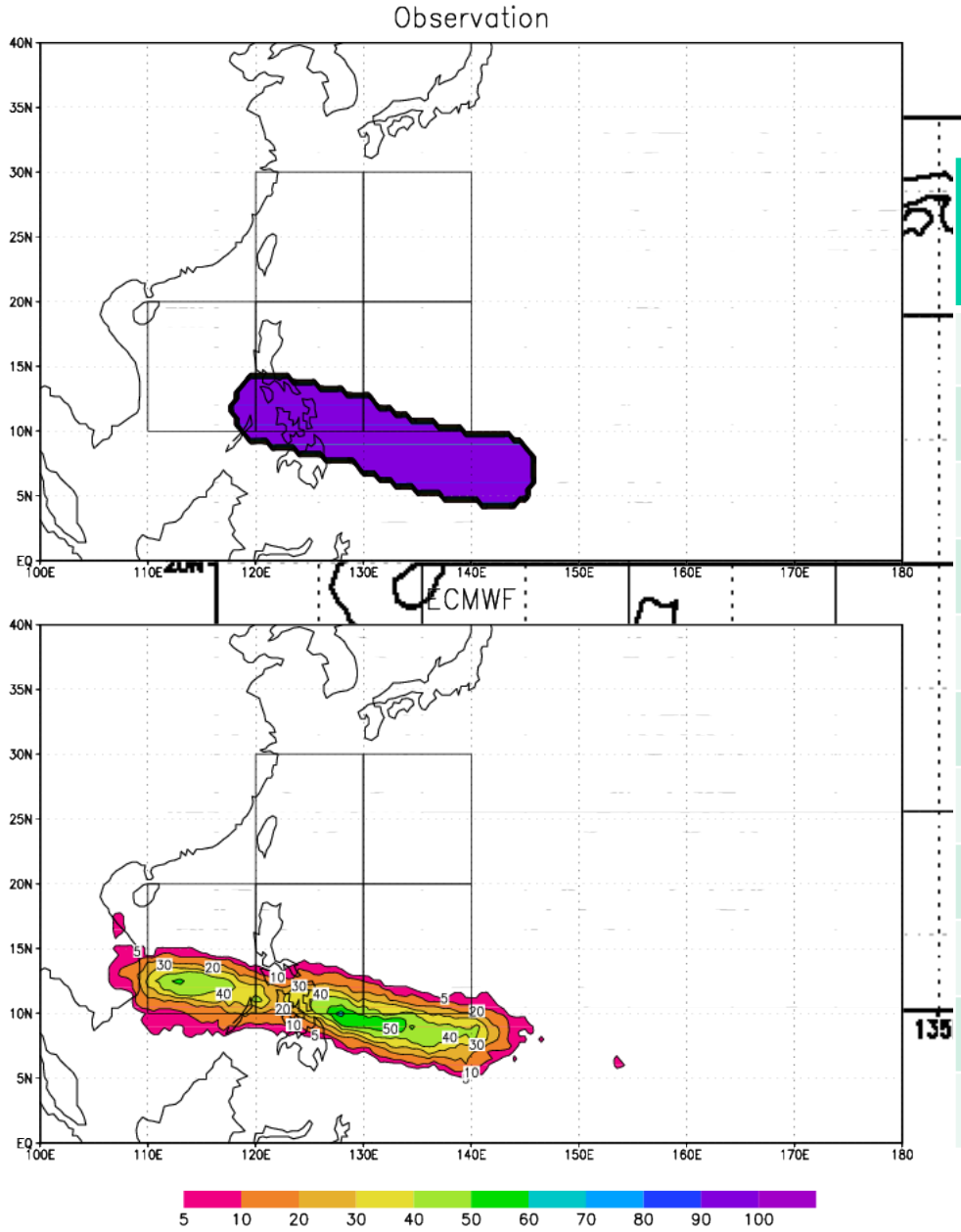






Climatological TC activity of this initial time and this forecast time window

Verification box



Probabilistic Contingency Table

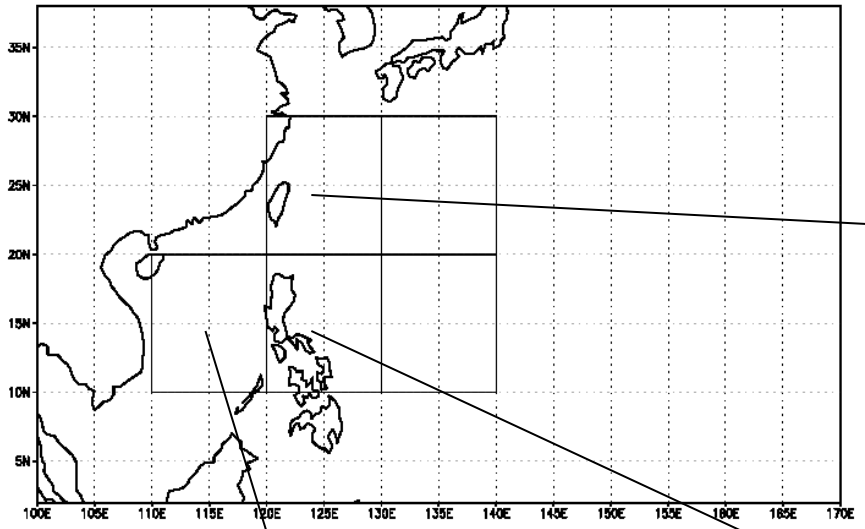
Forecast Probability	Observation	
	Yes	No
0 %	5541	209421
5%	6903	49809
15%	3463	9442
25%	2428	5532
35%	2147	3334
45%	1933	2026
55%	1621	1255
65%	1555	966
75%	1458	667
85%	1511	351
95%	1180	114

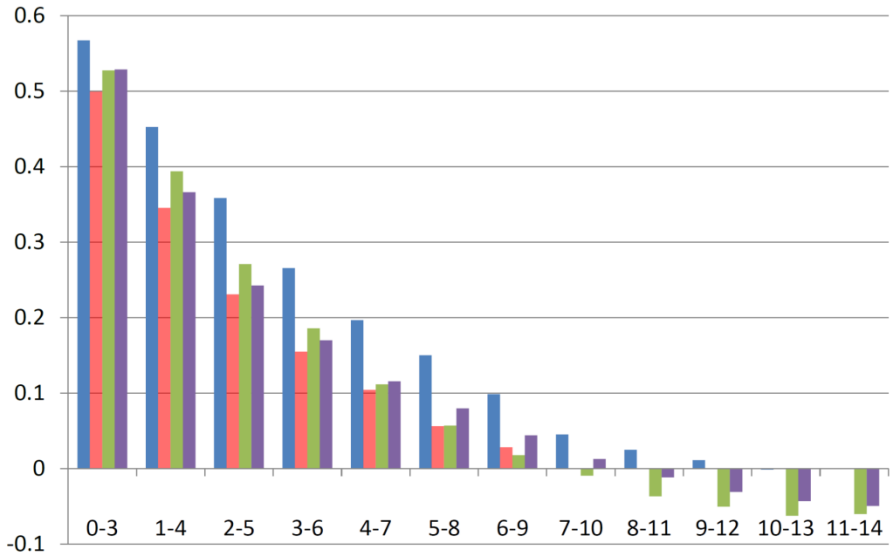
Why “activity” prediction, not “genesis” prediction?

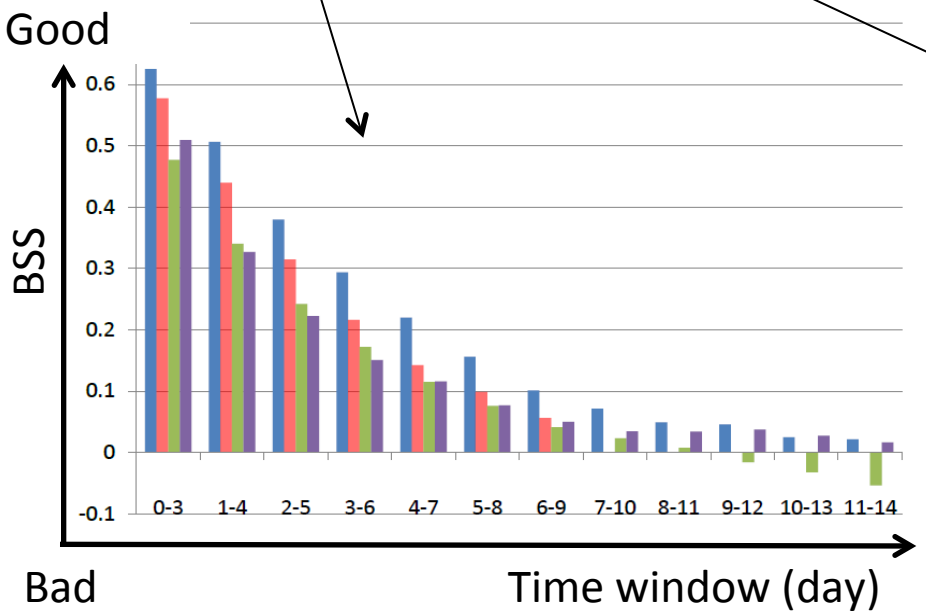
- It is difficult to define tropical cyclone genesis in the models because the representation of TCs depend on the models including their horizontal resolution.
- Reforecast data set would help calibrate model TCs, but TIGGE does not provide such data set.
- In addition, the horizontal resolution of TIGGE data set is not the same as the original one at each NWP center.
- 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.

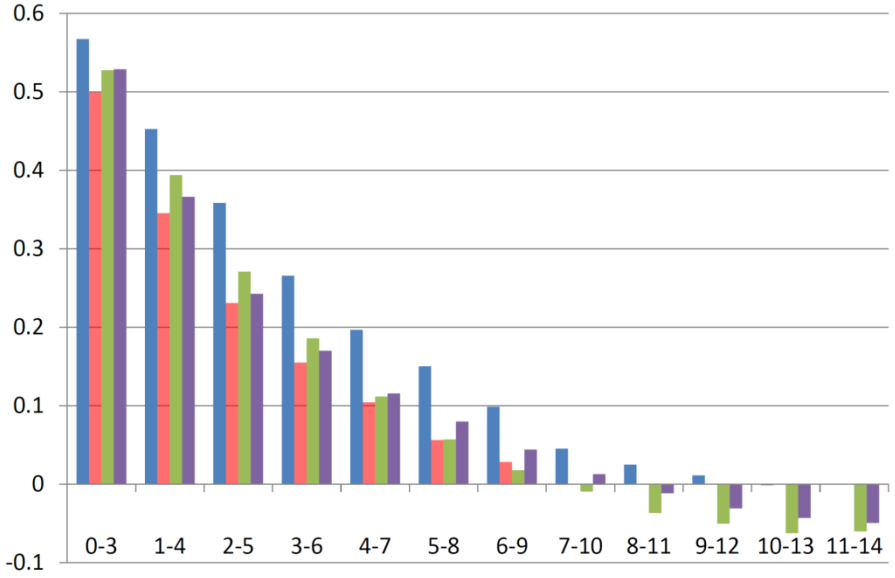
Verification of Tropical Cyclone Activity Prediction

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



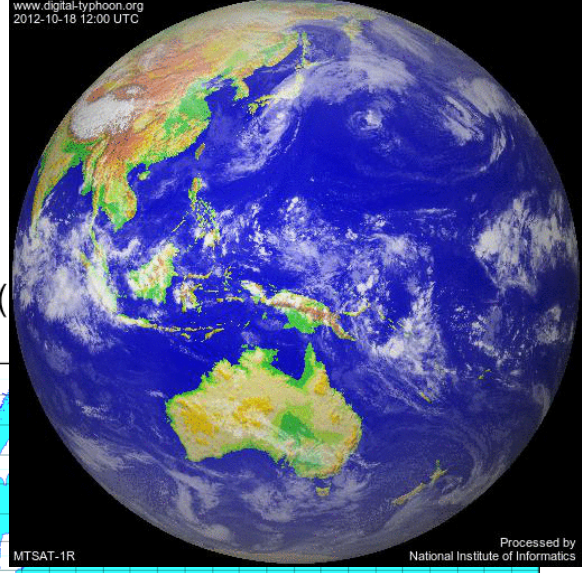




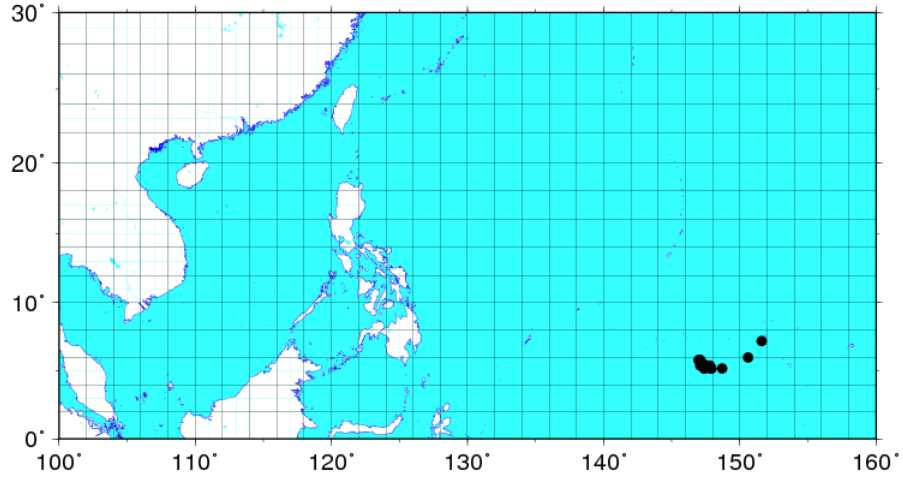


Case Study: Typhoon SON-TINH (2012)

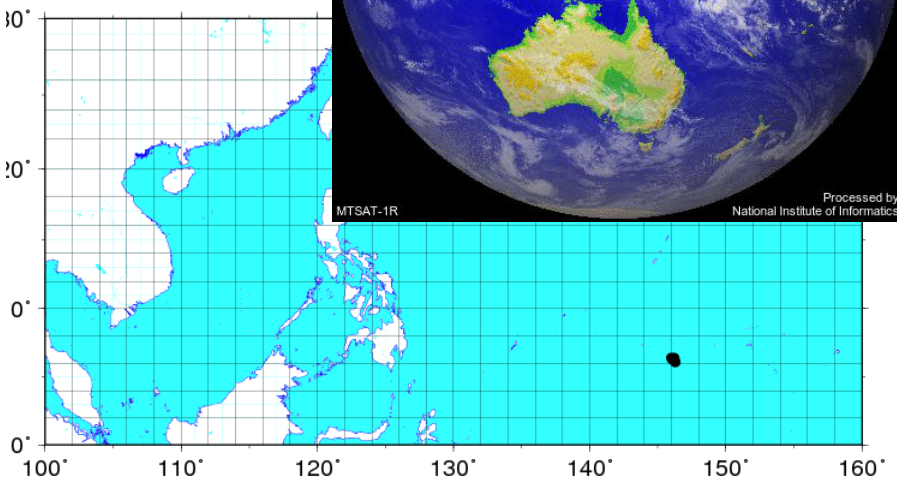
Black dots: detected ensemble storms from all ensemble members



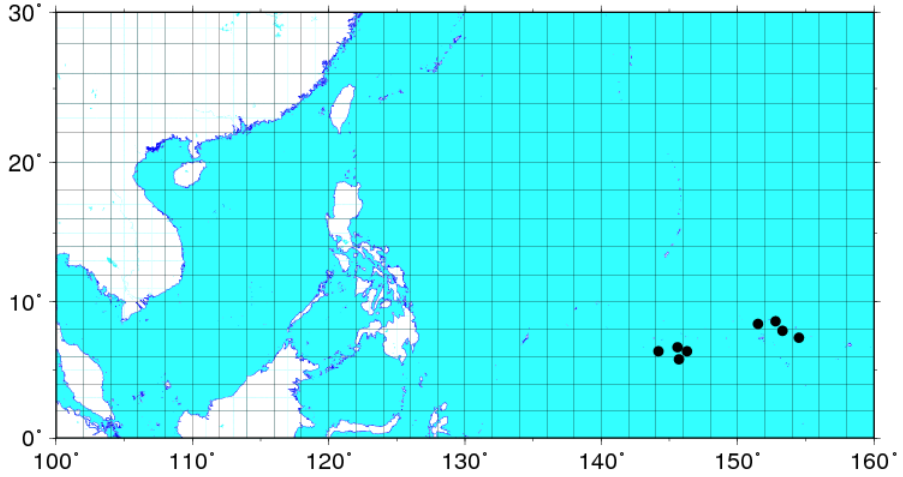
ECMWF FT=0days (–5days relative to genesis date)



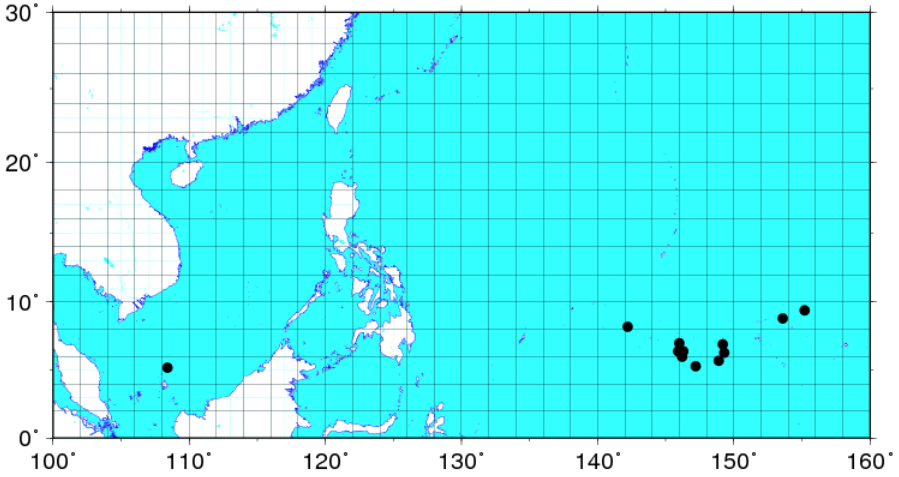
JMA FT=0days (



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



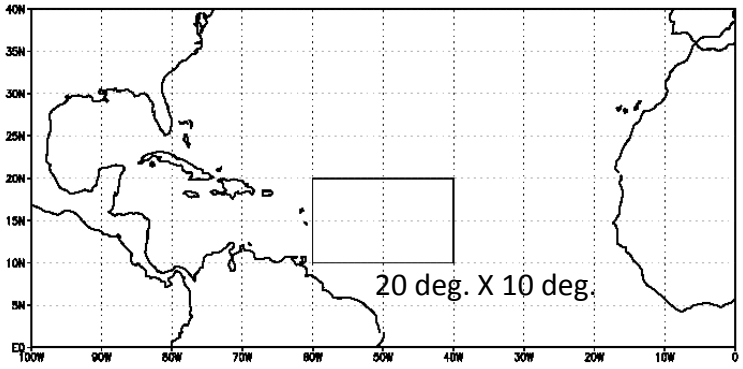
UKMO FT=0days (–5days relative to genesis date)

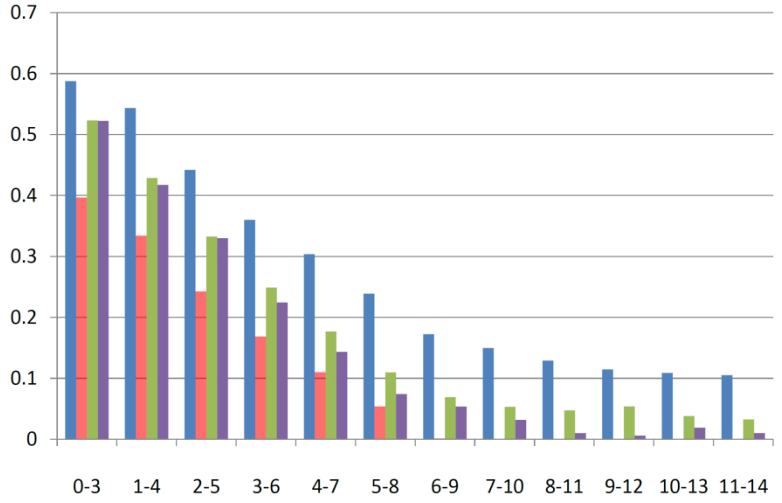


Future studies

•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.

•Extend the verification into the globe.





The same color bar definition as slide 26

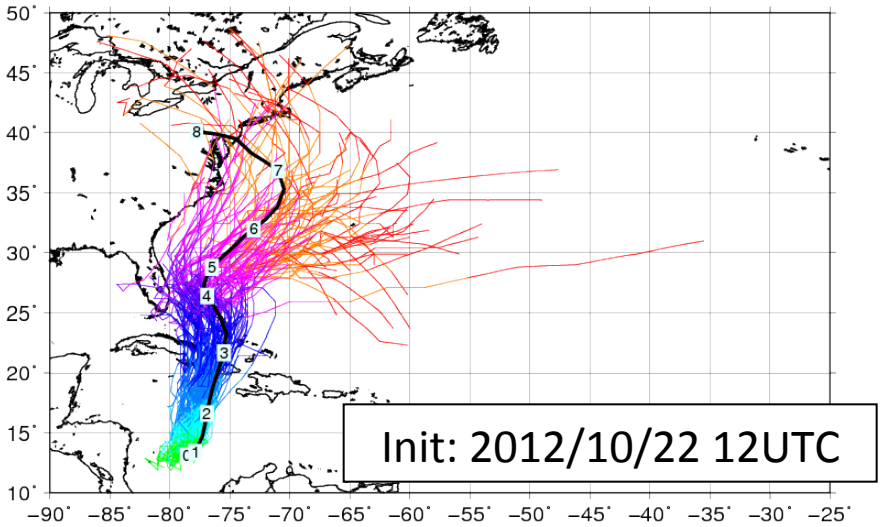
•Evaluate the relative benefit of multi-center grand ensemble wrt the best single model ensemble.

Hurricane Sandy, Cyclone Phailin and Typhoon Haiyan

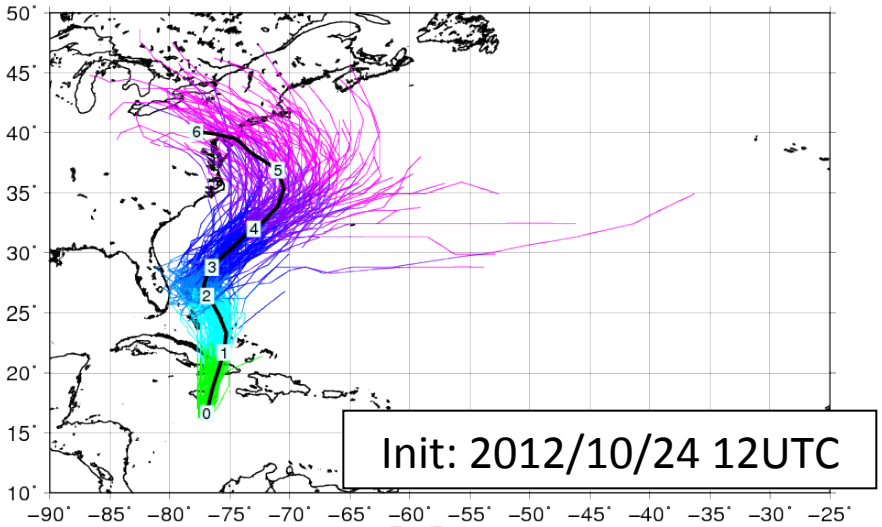
images are taken from wikipedia and bbc.co.uk

Hurricane Sandy

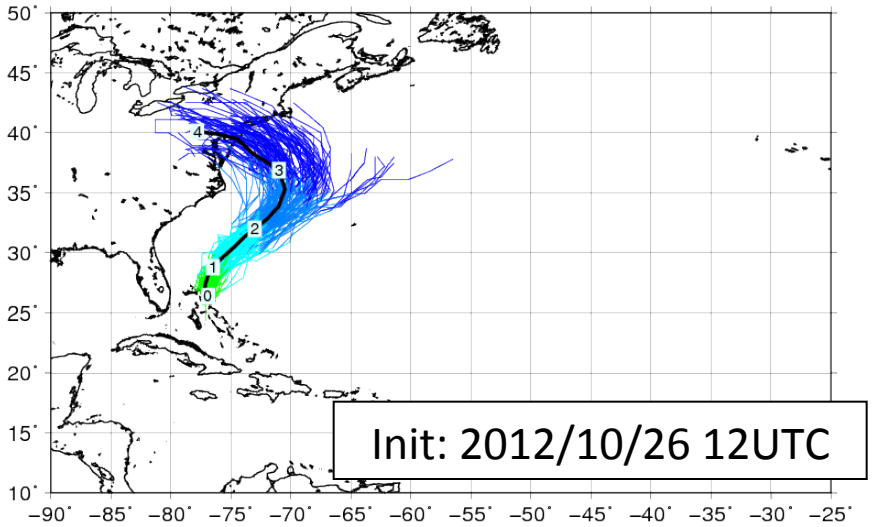
MCGE–4



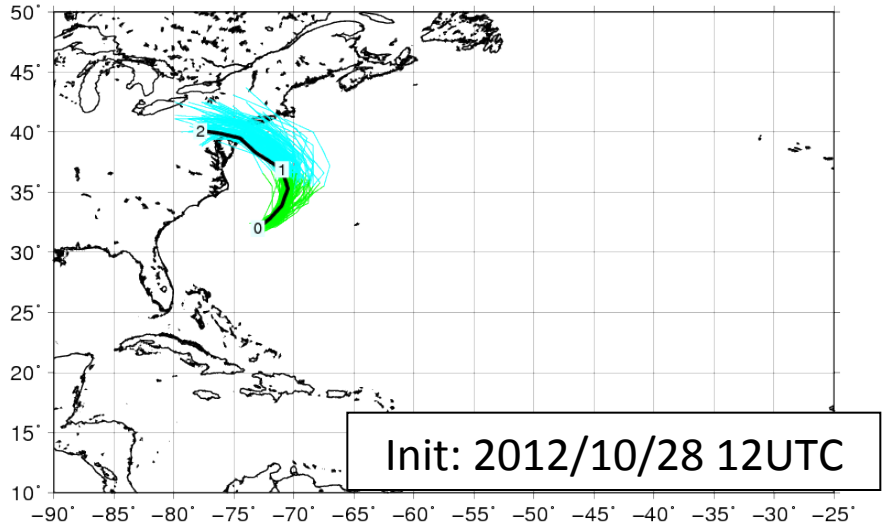
MCGE–4



MCGE–4

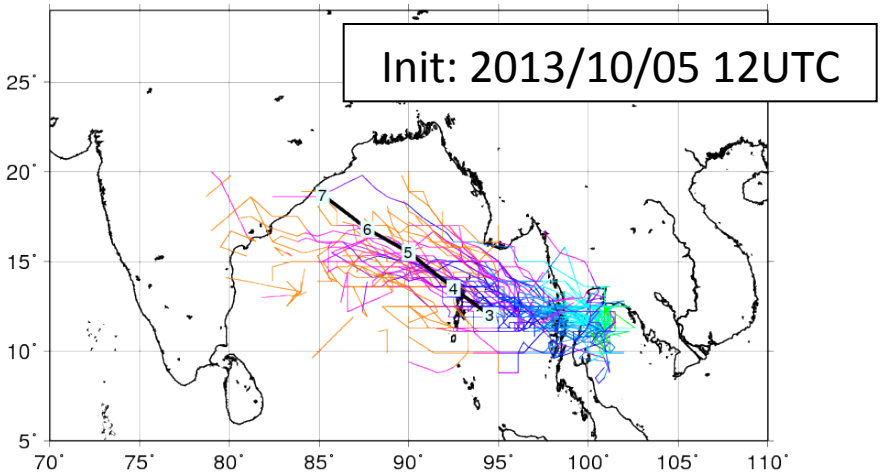


MCGE–4

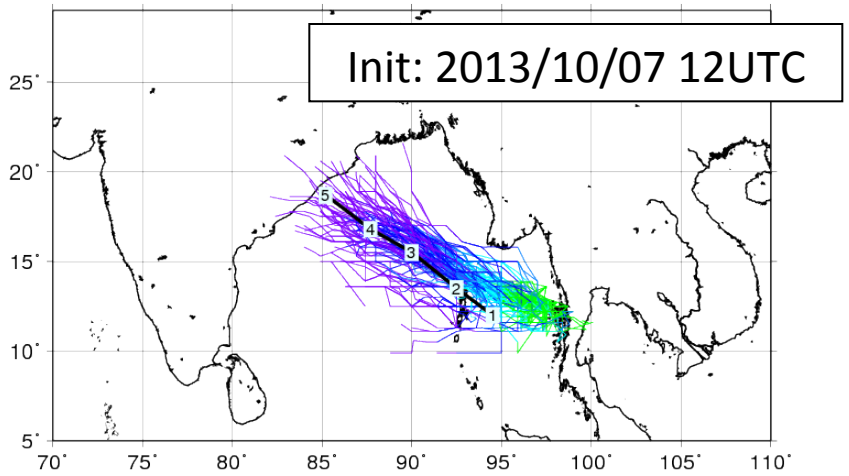


Cyclone Phailin

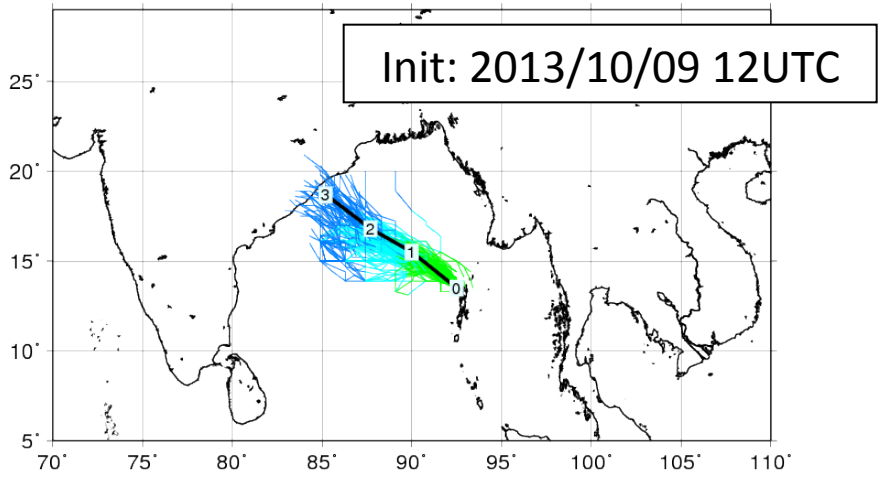
MCGE–4



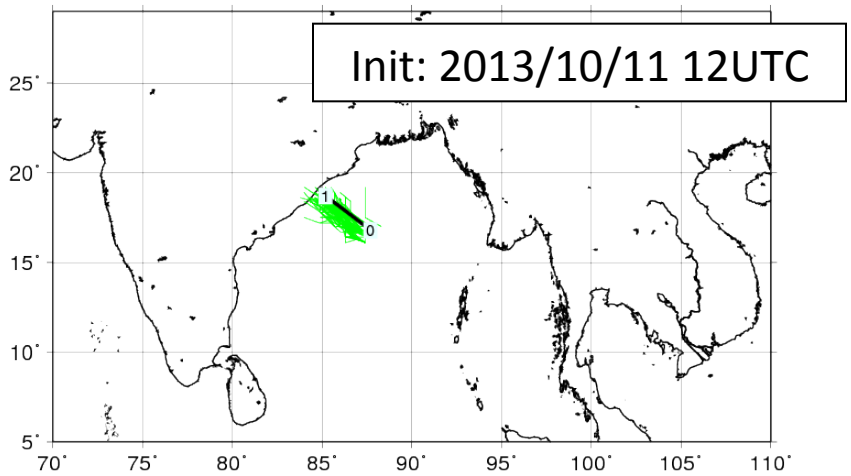
MCGE–4



MCGE–4

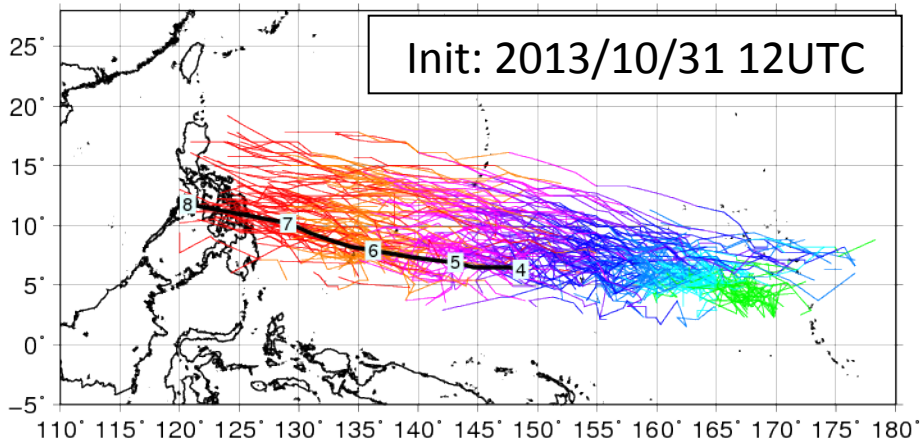


MCGE–4

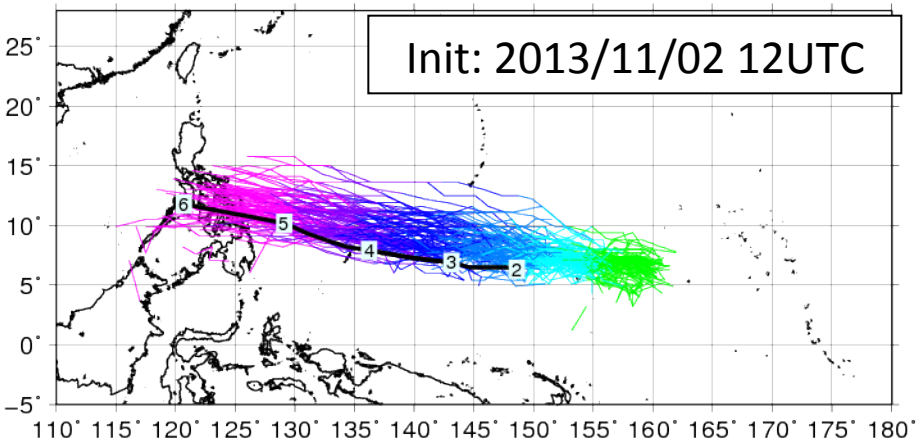


Typhoon Haiyan

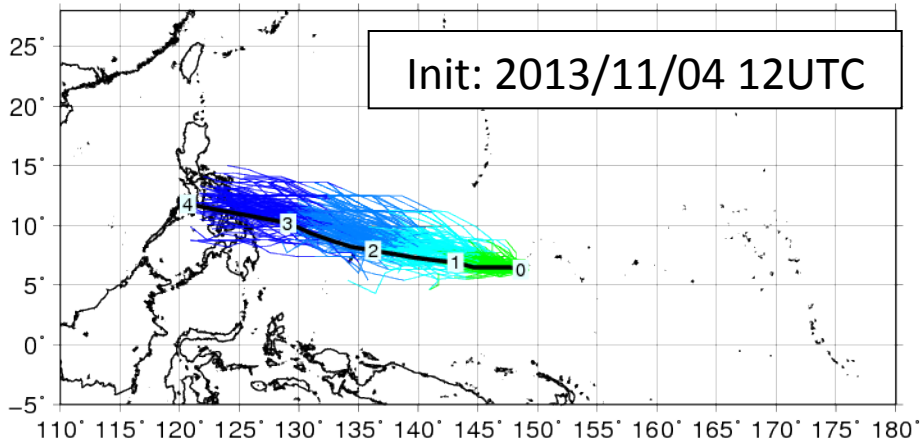
MCGE–4



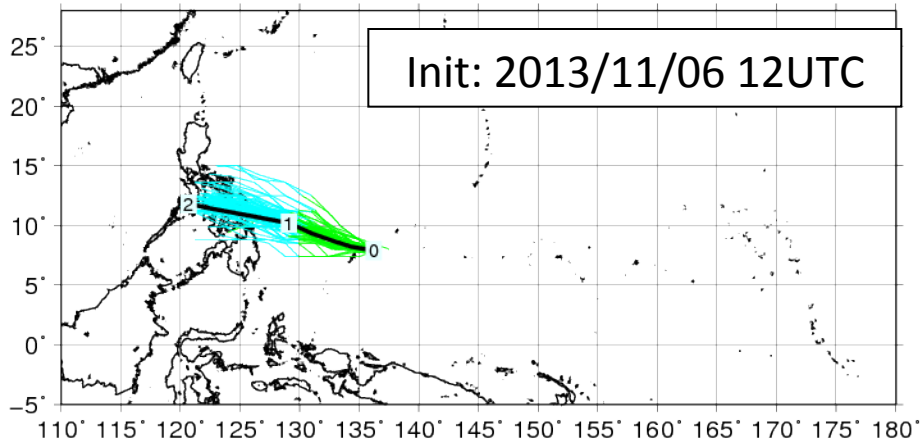
MCGE–4



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.**

- **In line with WGM AOP 2013, 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.

  - **For recent high-impact TCs, Hurricane Sandy, Cyclone Phailin and Typhoon Haiyan, MCGE TC track prediction predicted the landfall with high-confidence at least 5 days before the landfall.**

Supplementary slides

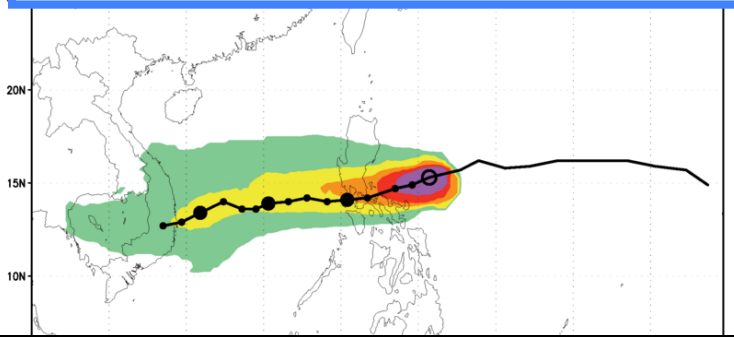
TC strike probability

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-

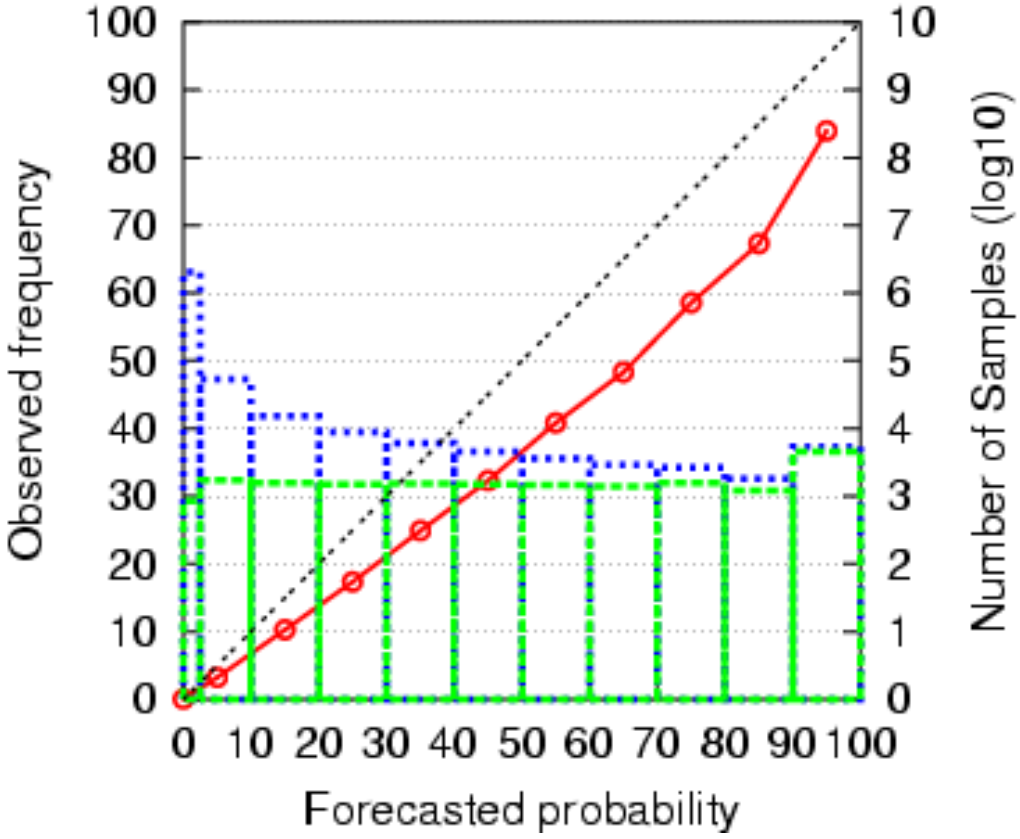


The strike probability is based on the number of members that predict the event with each member having an equal weight.

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.

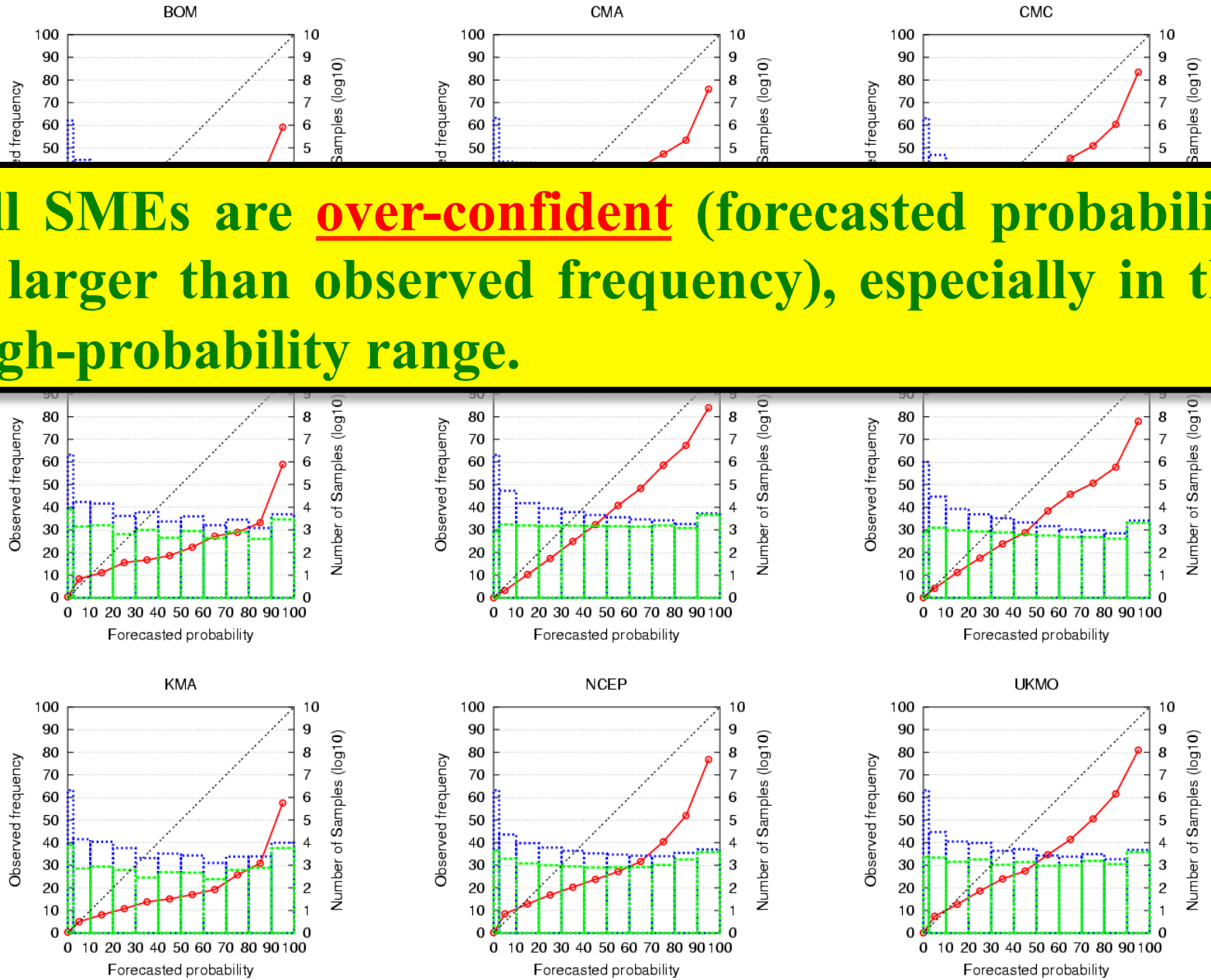
Reliability Diagram
-Verification for ECMWF EPS-



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

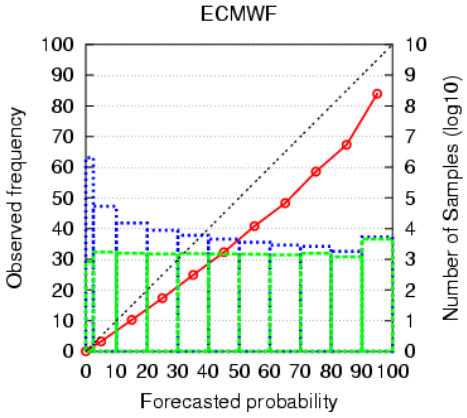
The number of samples (grid points) predicting the event is shown by **dashed blue boxes**, and the number of samples that the event actually happened is shown by **dashed green boxes**, corresponding to y axis on the right.

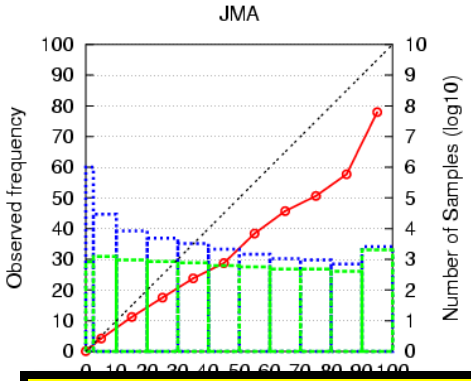
Verification result of TC strike probability -2-



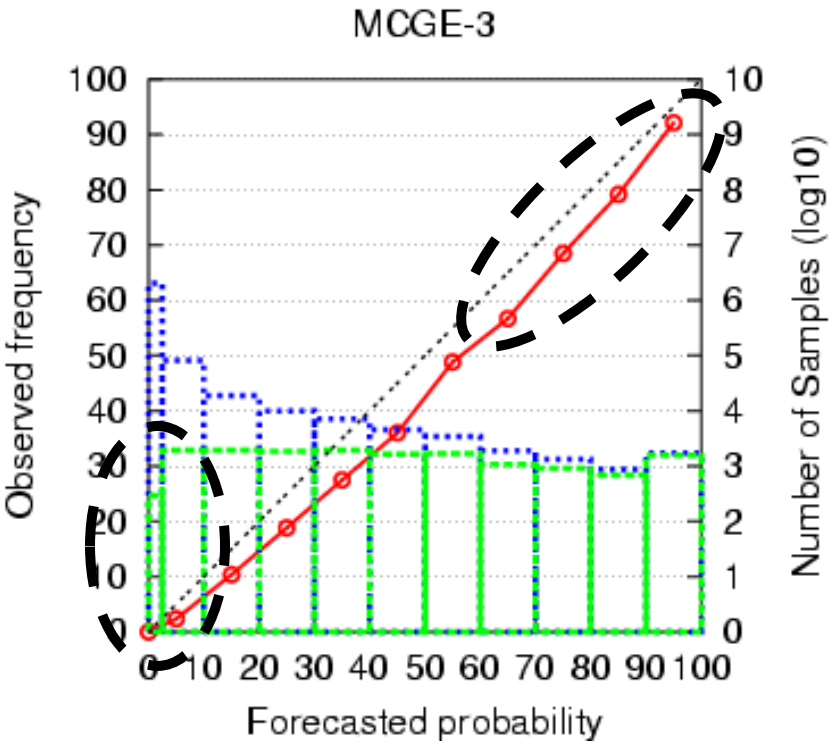
All SMEs are over-confident (forecasted probability is larger than observed frequency), especially in the high-probability range.

Benefit of MCGE over SME -1-





Combine 3 SMEs



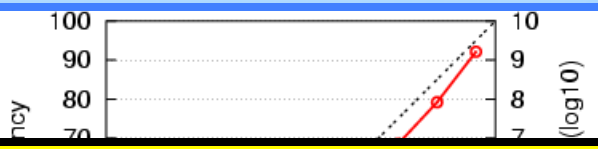
Reliability is improved, especially in the high-probability range.

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

Benefit of MCGE over SME -2-

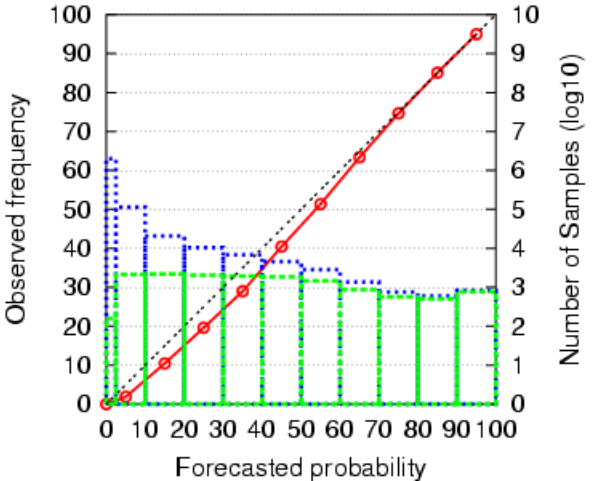
Best SME (ECMWF)

MCGE-3 (ECMWF+JMA +UKMO)

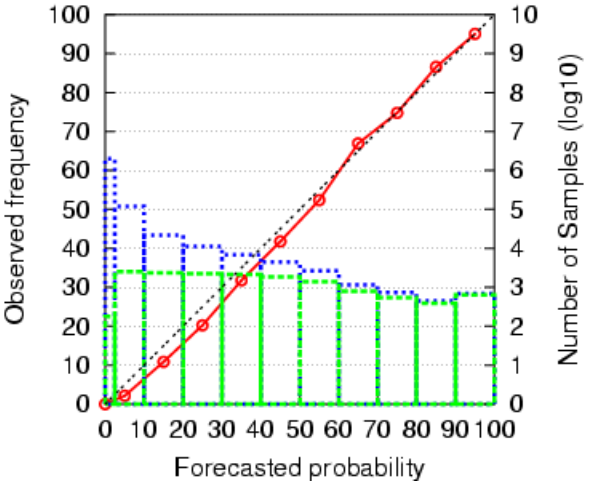


MCGEs reduce the missing area! The area is reduced by about 1/10 compared with the best SME. Thus the MCGEs would be more beneficial than the SMEs for those who need to avert missing TCs and/or assume the worst-case scenario.

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

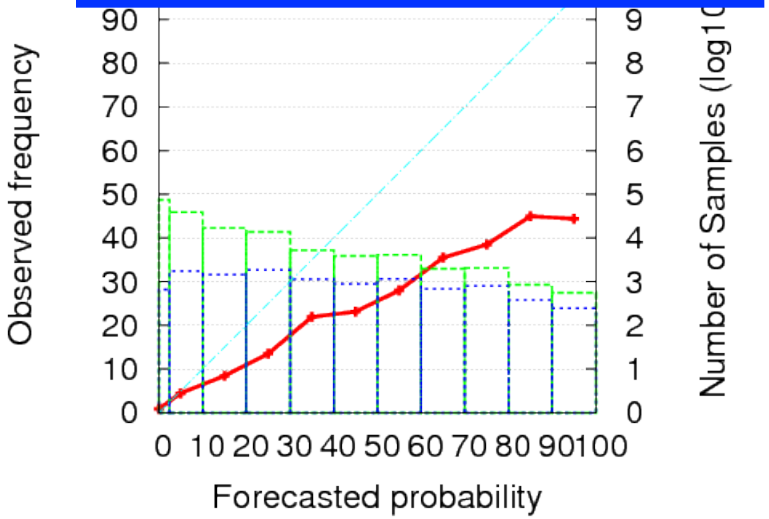


MCGE-9 (All 9 SMEs)

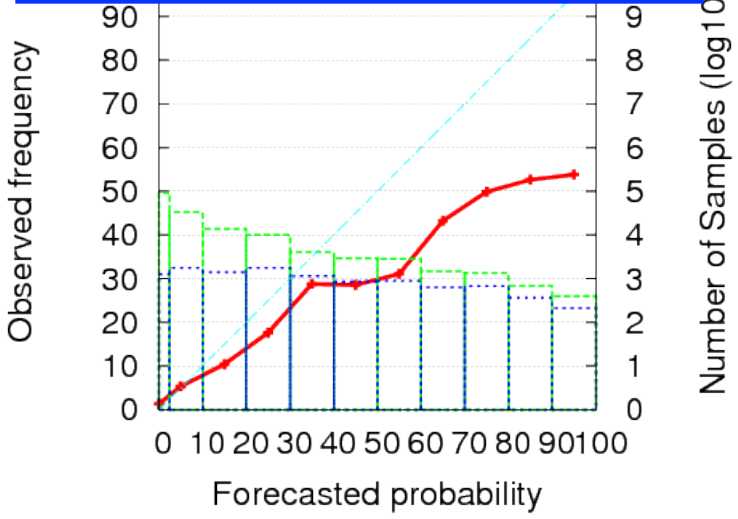


Reliability Diagram with different threshold (time window 3-6 days): AREA11

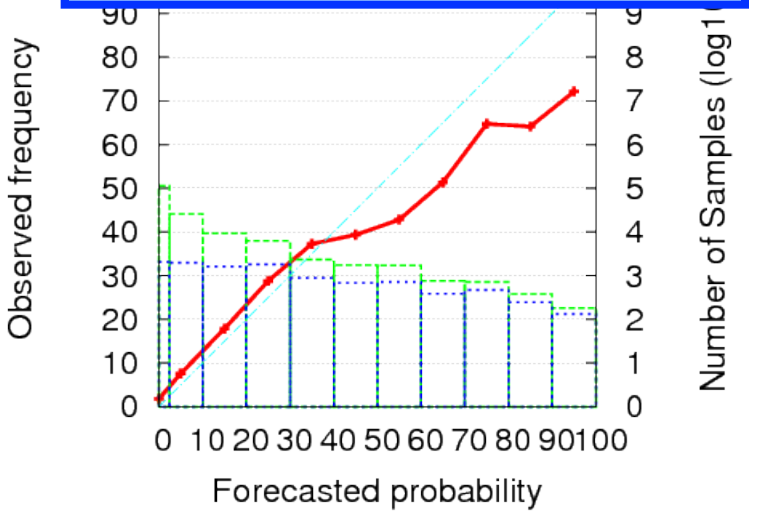
20kt



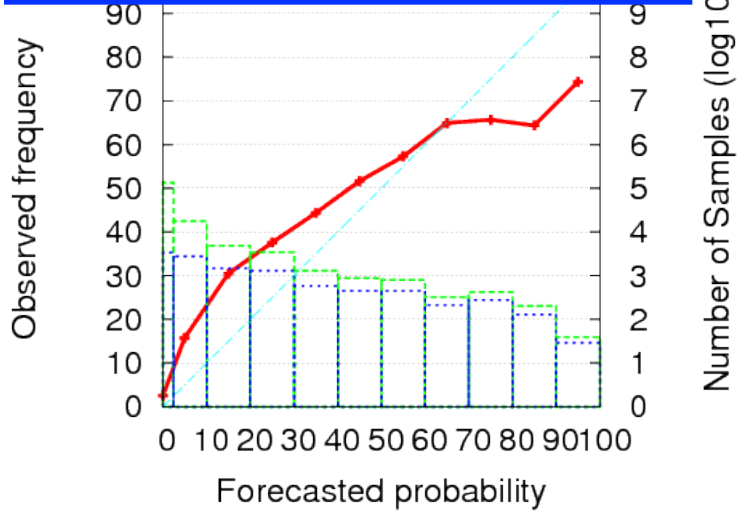
25kt

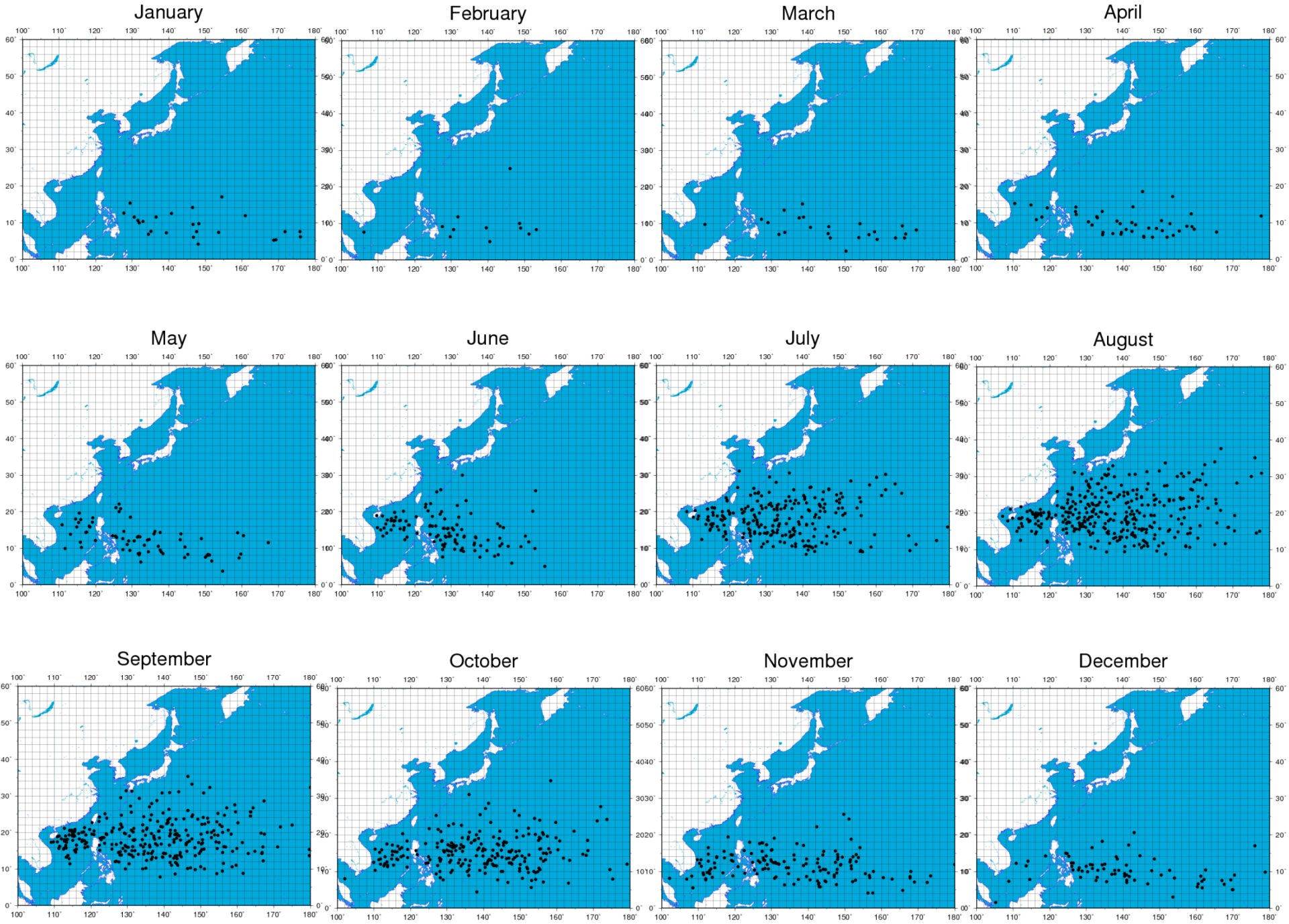


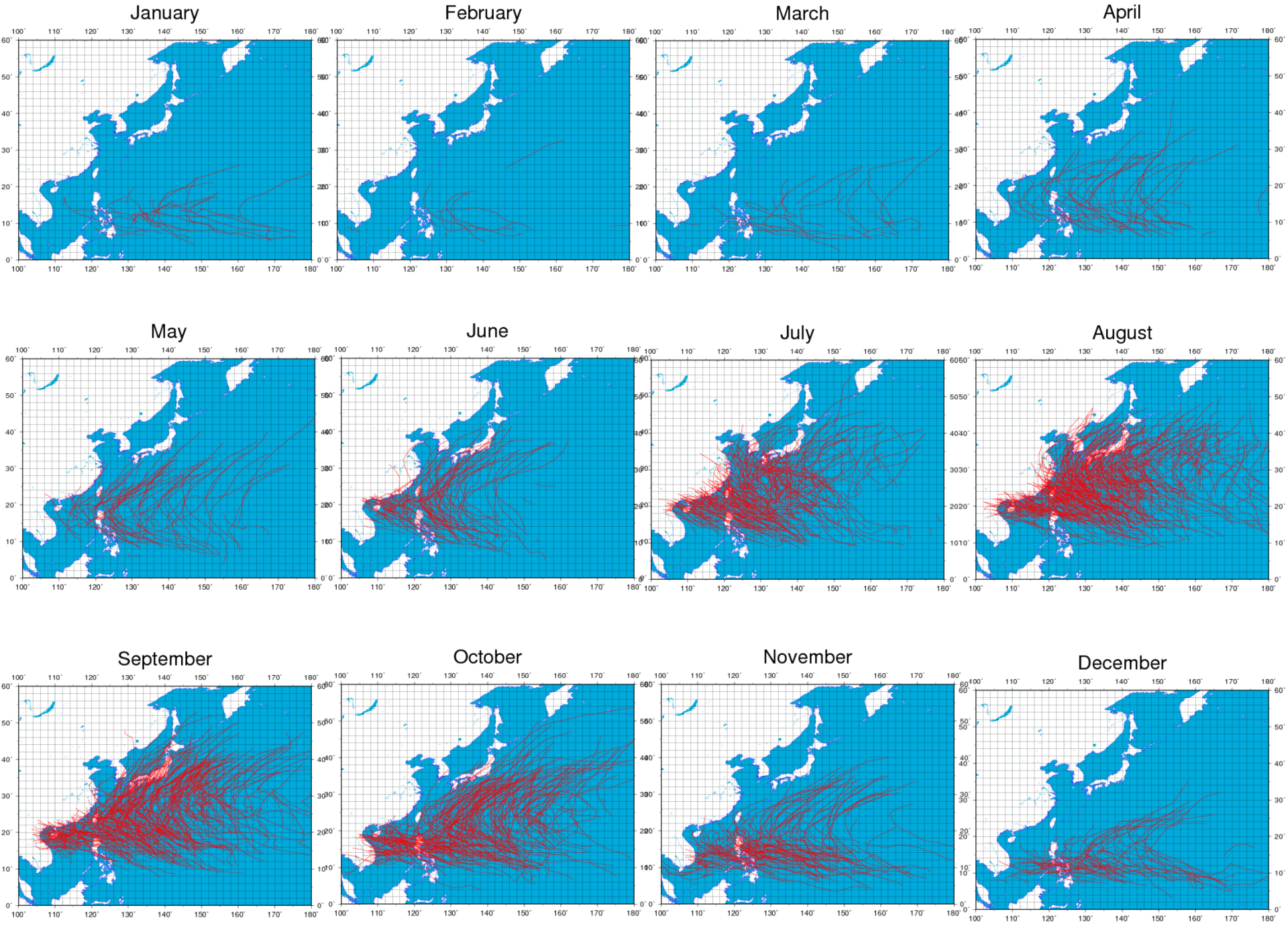
30kt (largest BSS)



35kt

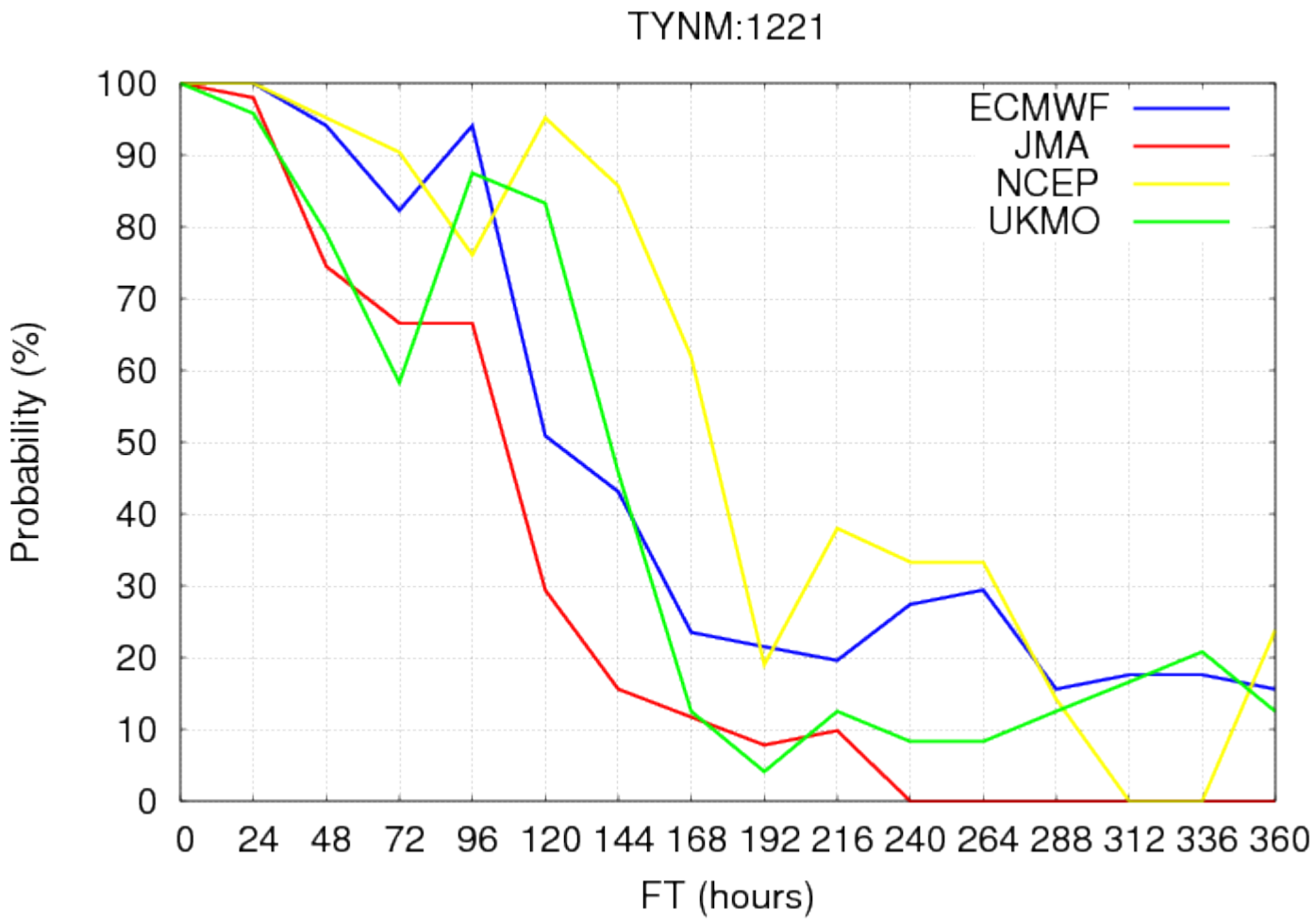



January
February
March
April
May
June
July
August
September
October
November
December


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

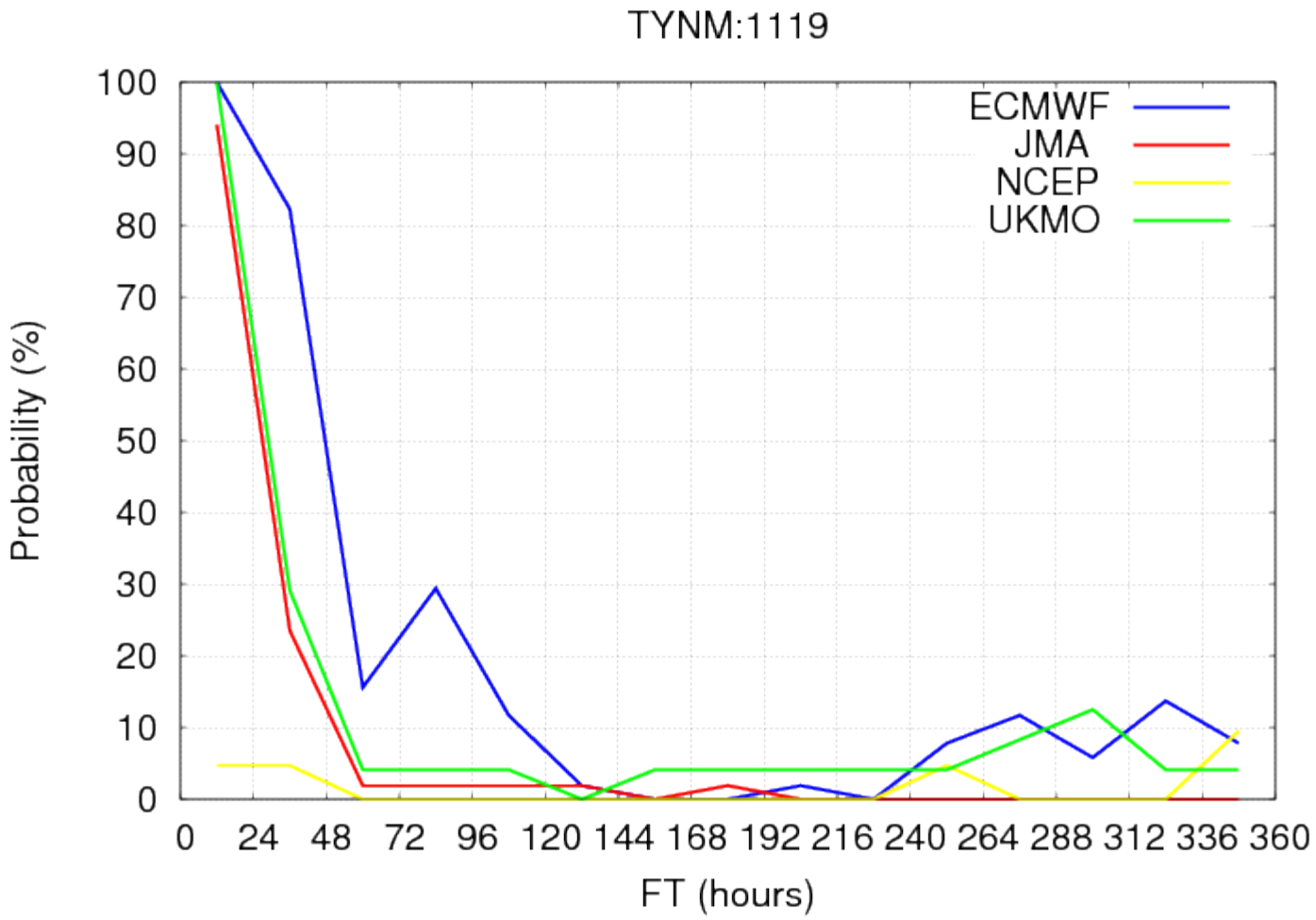
Typhoon PRAPIROON (2012)

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



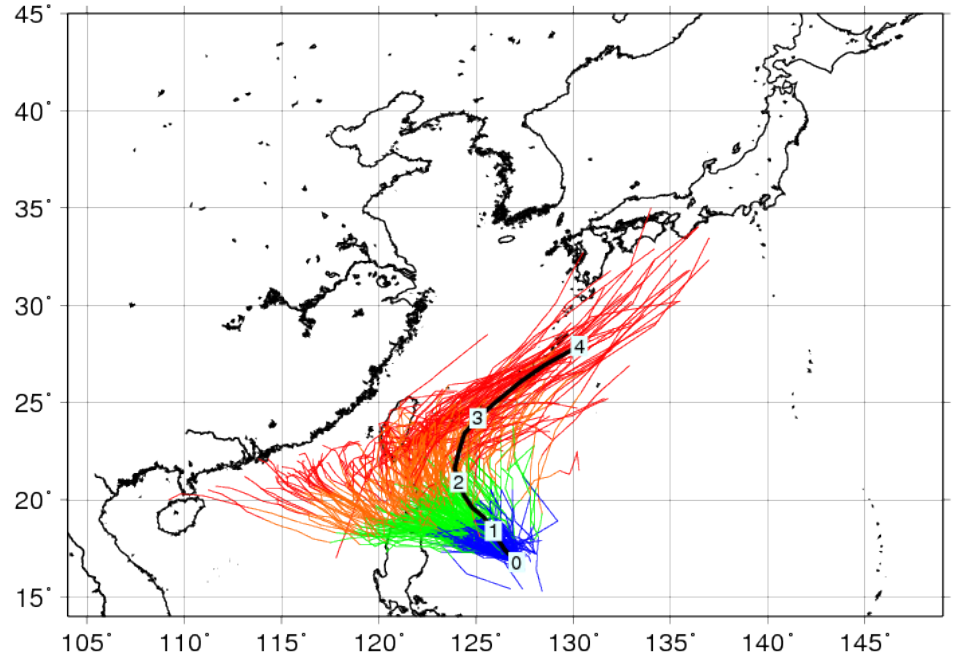
Typhoon NALGAE (2011)

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

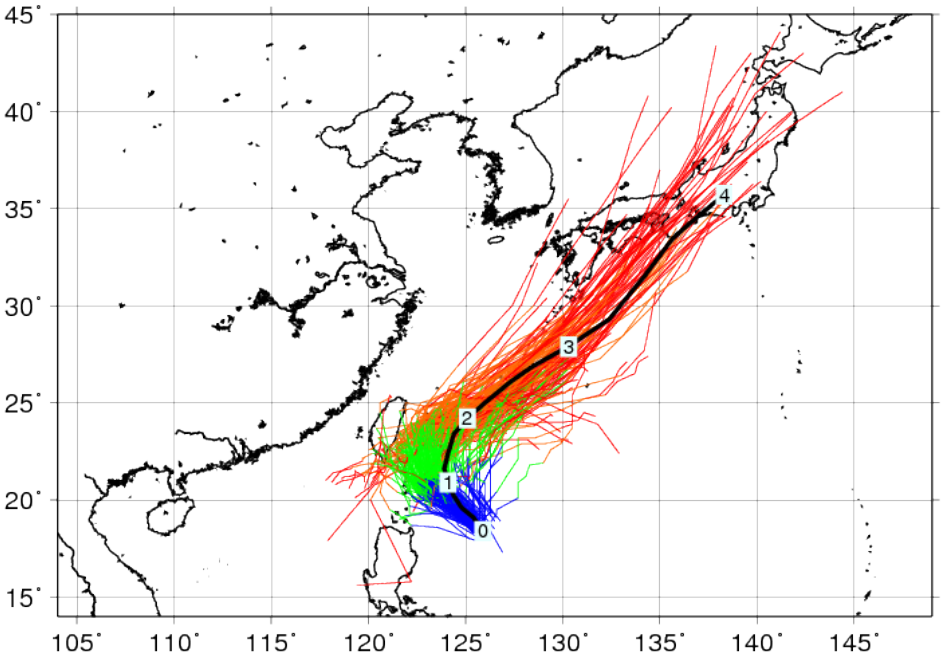


Forecast uncertainty changes day by day

Typhoon Jelawat
Init.: 2012.09.25 12UTC



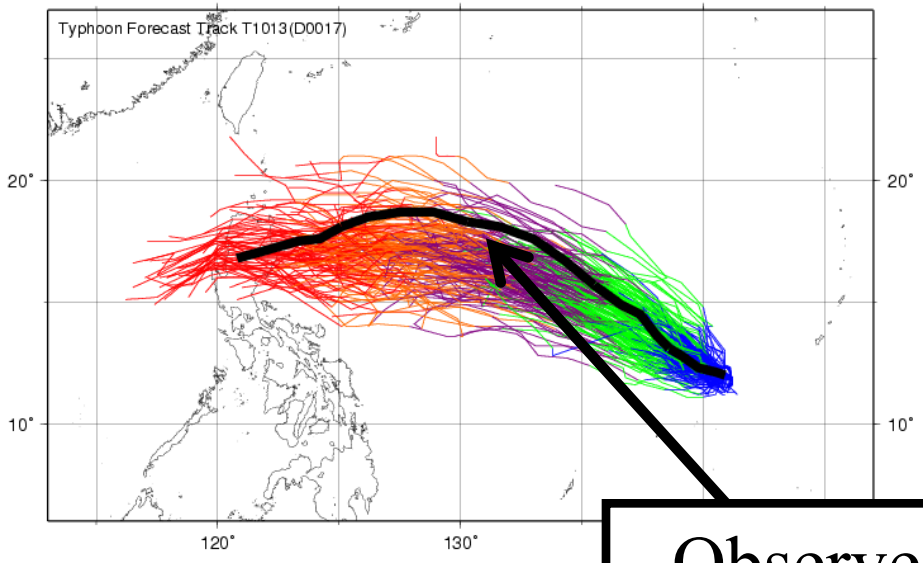
Typhoon Jelawat
Init.: 2012.09.26 12UTC



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

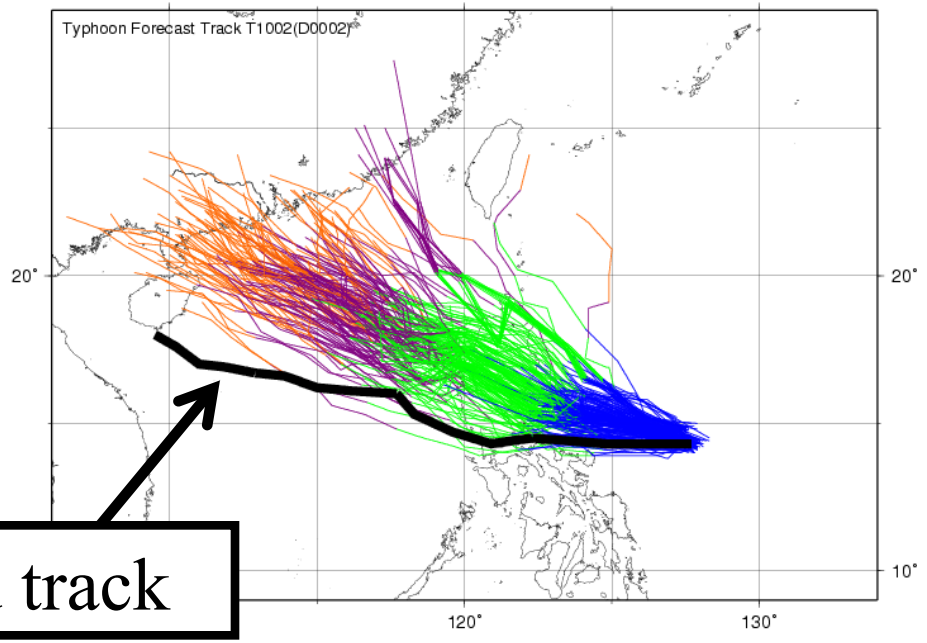
Good example

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



Bad example

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

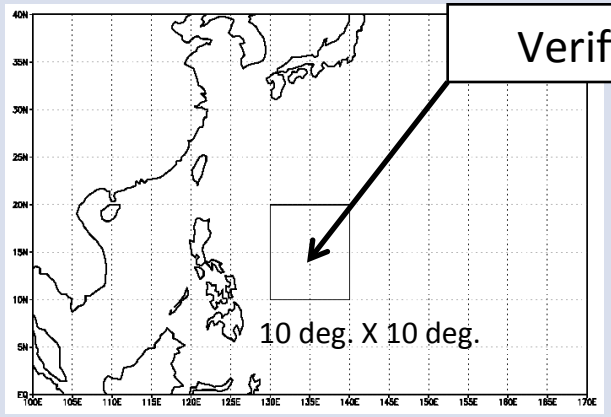
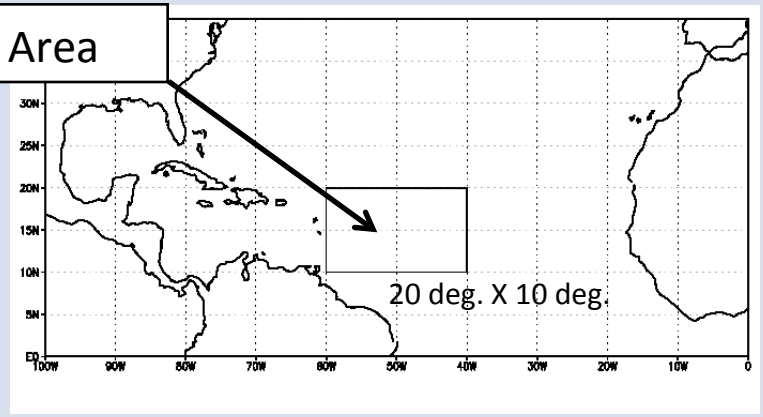


Observed track

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.

Verification of Tropical Cyclone Activity Prediction

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

	Western North Pacific	North Atlantic
Verif. Area		
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