Probability Circles Representing the Uncertainty of Tropical Cyclone Track Forecasts

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1. Introduction

In July 1997, the RSMC Tokyo – Typhoon Center of the Japan Meteorological Agency (JMA) started to provide three-day track forecasts of tropical cyclones (TCs) active over the western North Pacific and the South China Sea. To support this work, the Typhoon Ensemble Prediction System (TEPS; Kyouda and Higaki 2015) was put into operation in February 2008, and the track forecast time was extended to five days in April 2009. Track forecast uncertainty is expressed using circles to indicate expected TC locations at each forecast time with a probability of 70% (Mannoji 2005). For three-day forecasts, the radius is a function of the direction and speed of TC movement based on JMA historical track forecast errors as described in Section 2. For five-day forecasts, the radius is estimated using the cumulative ensemble spread of TC tracks calculated using TEPS as outlined in Section 3. Examples of probability circles with large and small spreads are given in Section 4.

2. Probability Circles for 3- to 72-hour Forecasts

The radius of the probability circle for 3- to 72-hour forecasts is a function of the direction and speed of TC movement at each forecast time. A look at TC center predictions made from 2004 to 2007 suggests that errors increased when the movement was faster and when the direction was between 260 and 359 degrees (clockwise with north as 0 degrees). Based on these statistics, the radius of the probability circle was determined as shown in Table 1.

Table 1. Radius of probability circle as a function of forecast time and direction/speed (V) of TC movement at each forecast time

Forecast time [h]	Direction of movement	Radius of probability circle [nm]		
		V ≤ 10 kt	10 kt < V ≤ 30 kt	V > 30 kt
3	All	20	20	35
6	All	30	30	50
9	All	40	40	70
12	All	50	50	85
15	260 - 359°	55	55	95
	360 - 259°	60	60	
18	260 - 359°	60	65	110
	360 - 259°	70	70	
21	260 - 359°	65	70	120
	360 - 259°	75	75	
24	260 - 359°	70	75	130
	360 - 259°	85	85	
48	260 - 359°	110	140	210
	360 - 259°	160	180	
72	260 - 359°	160	210	325
	360 - 259°	220	250	

3. Probability Circles for 96- and 120-hour Forecasts

The radius of the probability circle for 96- and 120-hour forecasts is determined using the cumulative ensemble track spread calculated from TEPS results. In this formulation, the ensemble spread calculated from the positions of TEPS members is a standard deviation with respect to the position of their ensemble mean. The ensemble spread is calculated every six hours and accumulated from the initial time to the forecast time. To give a snapshot of uncertainty at each forecast time and a history from the initial time, cumulative spread is employed for this estimation.

In April 2009 when JMA started to issue five-day TC track forecasts, the probability circle was based on TEPS with 11 ensemble members (Kishimoto 2010). Its radius was related to the TEPS forecast confidence level for each forecast time as high (A), medium (B) or low (C) in line with its cumulative ensemble track spread to make the rates of each population become 40%, 40% and 20%, respectively. The radius was then determined based on a relationship with the TEPS forecast confidence level.

A major modification of the TEPS including an increase in the number of ensemble members from 11 to 25 and a decrease in the horizontal grid spacing from about 55 km to 40 km in March 2014 made the ensemble TC track spread smaller than that of the previous system (Kyouda and Higaki 2015). To reflect this change in the ensemble spread, the relationship between the radius of the probability circle and the cumulative ensemble spread was re-verified based on the results of pre-operational tests for the new TEPS with 25 members. The tests targeted every TC observed from 2011 to 2013. Figure 1 shows the sorted distribution of the cumulative ensemble spread for 72-hour forecasts from the new TEPS and thresholds representing 40% and 80% frequencies. Calculating the thresholds for each forecast time in the same manner as Kishimoto (2010) gives the threshold curves given in Fig. 2, which also shows curves based on the previous version of TEPS.

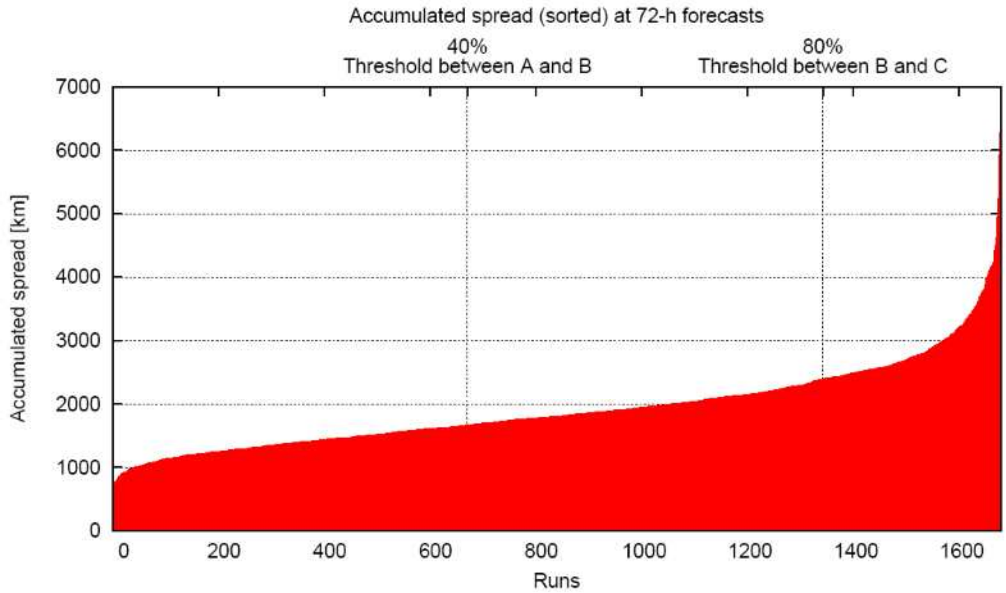

Figure 1. Sorted distribution of cumulative ensemble spread for 72-hour forecasts. The vertical lines represent the 40th and 80th percentile thresholds.

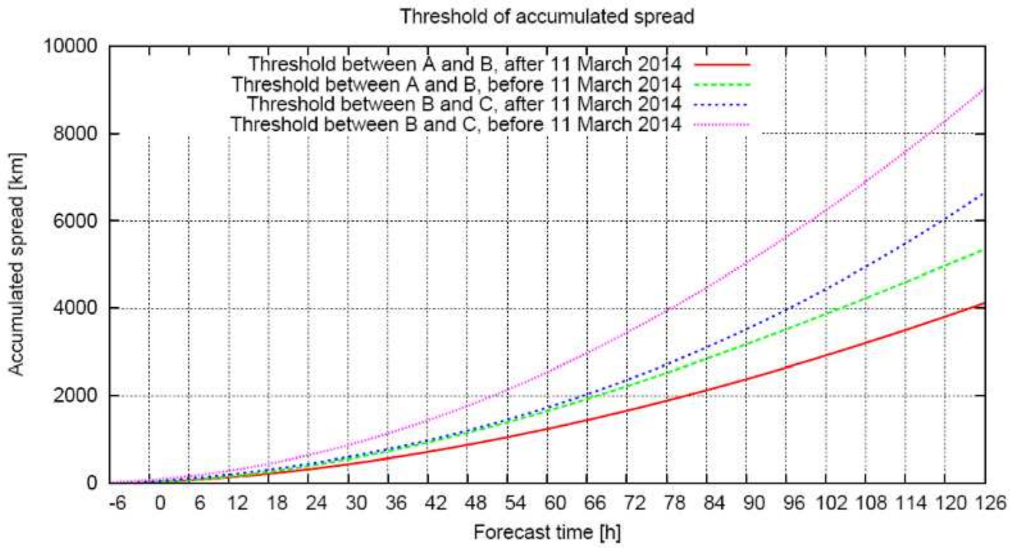

Figure 2. Threshold curves representing the uncertainty of TC track forecasts

4. Large- and Small-spread Cases

Figures 3 and 4 show (a) TC tracks from TEPS runs started at 00 UTC on 2 October and 00 UTC on 10 October 2014, (b) cumulative ensemble spread calculated from these tracks, and (c) probability circles determined using the spread and issued at 06 UTC on 2 October and 06 UTC on 10 October 2014. It is clear that the spread of TC tracks in Fig. 3 is larger than that in Fig. 4.

Using the threshold shown in Fig. 2, the radius of the probability circle for the 120-hour forecast in the large-spread case is 450 nm (850 km; Fig. 3 (c)). Meanwhile, that for the small-spread case is 375 nm (700 km; Fig. 4 (c)), which is 82% smaller.

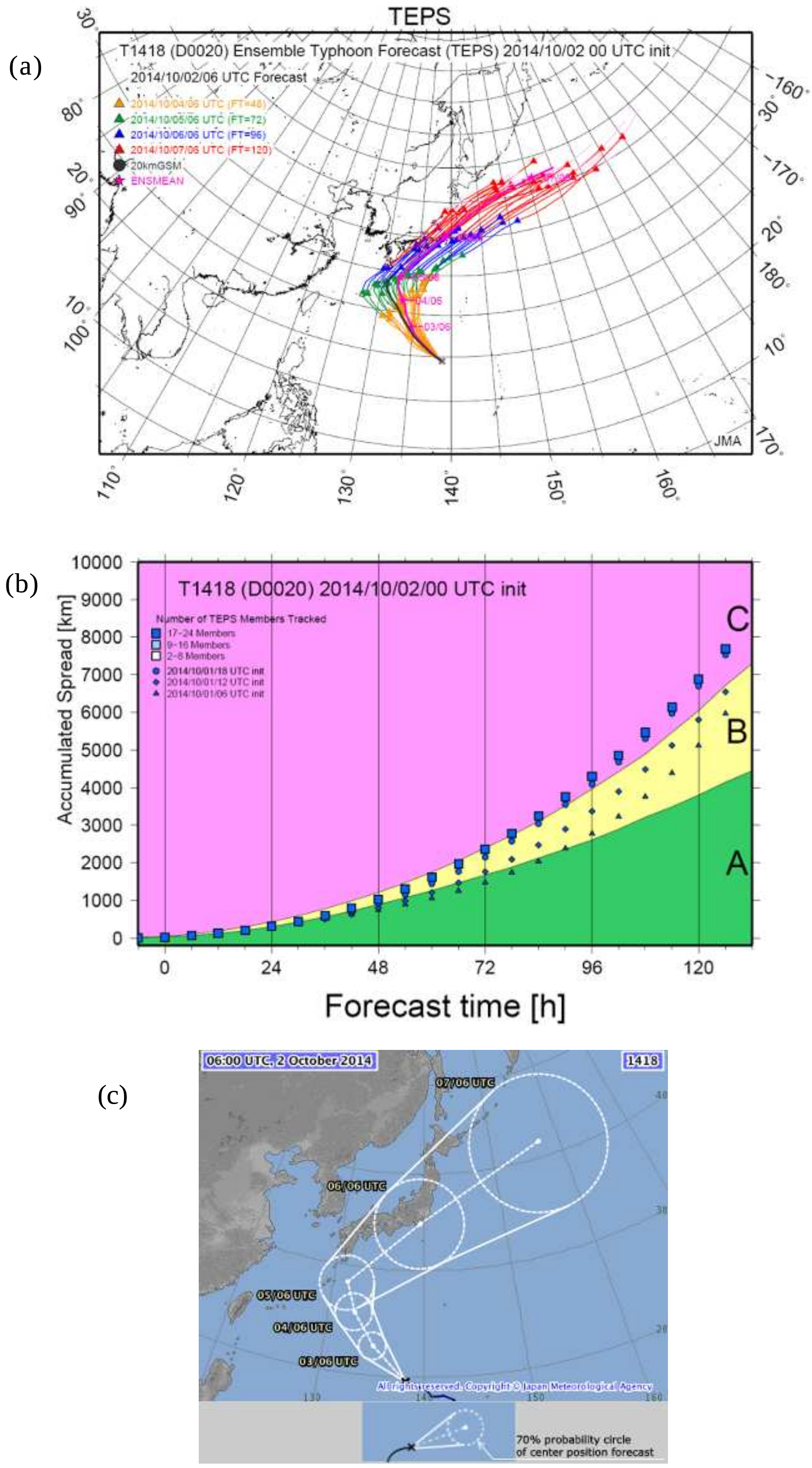

Figure 3. (a) TC tracks from a TEPS run started at 00 UTC on 2 October 2014; (b) cumulative ensemble spread; and (c) probability circles determined from the spread

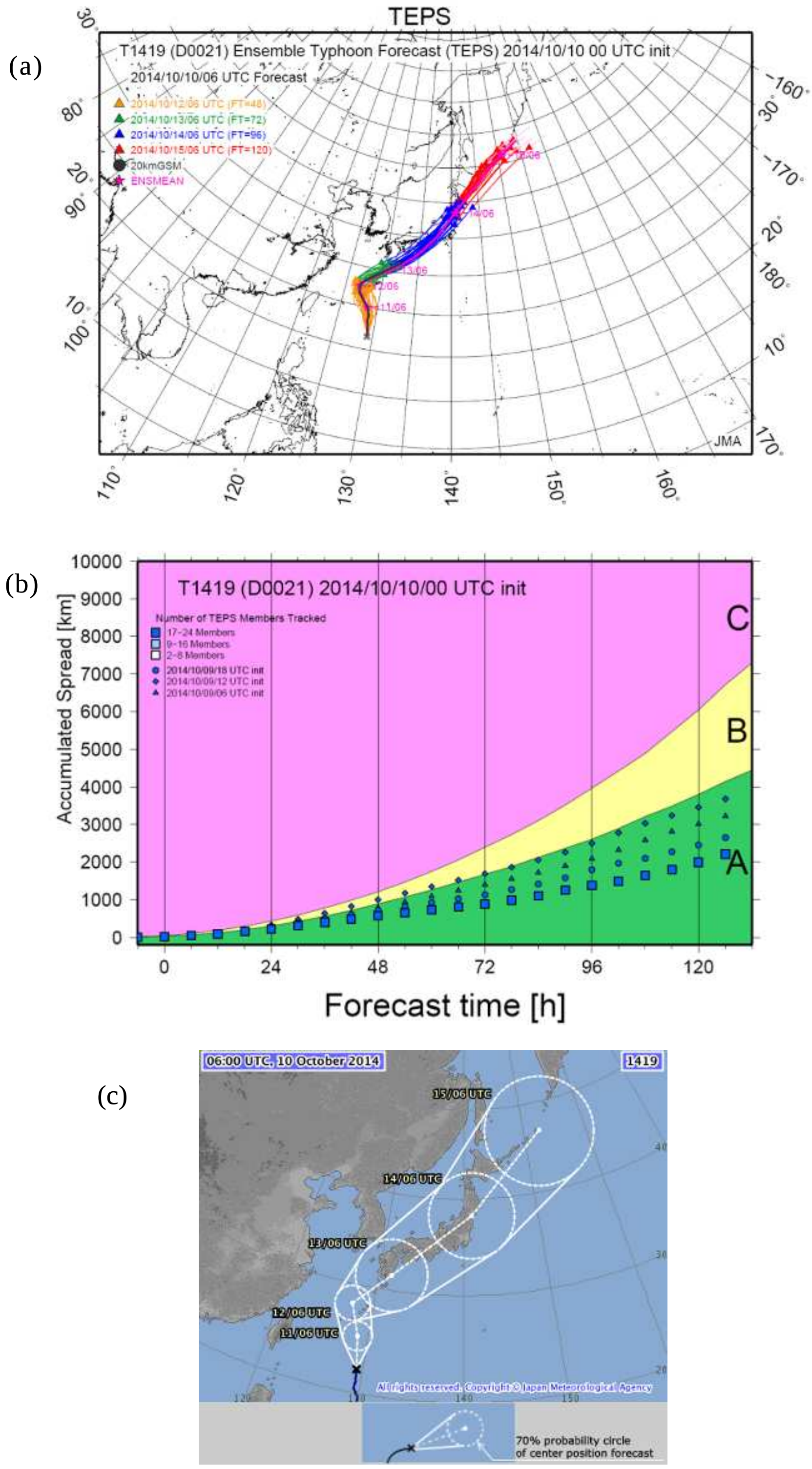

Figure 4. (a) TC tracks from a TEPS run started at 00 UTC on 10 October 2014; (b) cumulative ensemble spread; and (c) probability circles determined from the spread

5. Further work

As described in Sections 2 and 3, the radii of probability circles for 3- to 72-hour forecasts and 96- and 120-hour forecasts are determined in different ways. The former are based on the direction and speed of TC movement at each forecast time, while the latter are based on the cumulative ensemble track spread calculated from TEPS results. As this can cause unreasonable discrepancies between forecast times before and after 72 hours, operational forecasters often need to adjust radii subjectively in line with expected forecast uncertainties. The hit ratios of probability circles are verified annually and reported in the Annual Report on Activities of the RSMC Tokyo – Typhoon Center (http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/annualreport.html). In future work, ensemble spread-based probability circles for the whole forecast time need to be developed because TC movement alone does not appear to sufficiently represent forecast uncertainty from a statistical or physical viewpoint.

6. Summary

Since July 1997, the RSMC Tokyo – Typhoon Center of the Japan Meteorological Agency has issued three-day track forecasts of tropical cyclones (TCs) active over the western North Pacific and the South China Sea. In April 2009, the track forecast time was extended to five days. Track forecast uncertainty is expressed using probability circles with radii based on TC direction and speed at each forecast time for 3- to 72-hour forecasts and on cumulative ensemble track spread calculated from the Typhoon Ensemble System (TEPS) for 96- and 120-hour forecasts. As the enhancement of TEPS in March 2014 resulted in reduced cumulative ensemble track spread, confidence level thresholds were modified.

References:

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