15D.7 WESTERN NORTH PACIFIC TROPICAL CYCLONES IN THE ECMWF 32-DAY ENSEMBLE PREDICTION SYSTEM

Hsiao-Chung Tsai *, Russell L. Elsberry, Mary S. Jordan
Naval Postgraduate School, Monterey, California USA

1. INTRODUCTION

The European Center for Medium-range Weather Forecasts (ECMWF) integrates medium-range deterministic and the Variable Ensemble Prediction System (VarEPS) for tracks of tropical cyclones that are already present in the initial conditions (van der Grijin et al. 2005). The next generation of ECMWF products will include an extension of the tracking and strike probability maps from five to ten days and probabilistic information on the storm intensity (Vitart et al. 2012). A similar display of the tropical cyclone activity within 300 km will be available from the ECMWF 32-day ensemble forecasting system. Vitart (2009) had attributed the skill of these activity forecasts to the ability of the ECMWF ensemble model to predict the Madden-Julian Oscillation (MJO). Vitart et al. (2010) had compared the ECMWF ensemble forecasts of weekly tropical activity in the Southern Hemisphere with a statistical model and found comparable or better skill to three weeks.

Belanger et al. (2010) examined the predictability of North Atlantic tropical cyclones using the 32-day ECMWF ensemble forecasts during the 2008 and 2009 seasons. Predictability to 15-21 days was indicated in the Main Development Region for Atlantic tropical cyclones. Elsberry et al. (2010) evaluated the predictability of western North Pacific tropical cyclone formations and tracks during the 2008 season using the 32-day ECMWF ensemble forecasts. Rather than a strike probability approach, they combined similar member vortex tracks and used a Weighted Mean Vector Motion technique (WMVM; Elsberry et al. 2008) to form ensemble storm tracks. Elsberry et al. (2011) examined the more typical and active 2009 season using the same approach and found an improved performance in predicting formations and tracks of the typhoons and even for most of the tropical depressions.

Elsberry et al. (2010 and 2011) used a two-step objective plus subjective approach for verifying the ensemble storm tracks relative to the Joint Typhoon Warning Center (JTWC) best-tracks. Their approach was to first treat the JTWC track as another storm and compare all of the applicable forecast ensemble storms at each 12 h forecast time to determine if at least one point on the ensemble storm track matched within a separation distance with the JTWC position at exactly that 12 h time. Second, a subjective assessment was made to assign a quality metric (Excellent, Above Average, Good, Below Average, and Poor) of the match of the ensemble storm to the JTWC track. This assessment focused more on the entire JTWC and ensemble storm tracks to avoid incidental agreement either early or late in the track. However, a certain degree of arbitrariness and person-dependency was involved in this assessment in terms of an Excellent quality metric versus an Above Average, etc.

The purpose of this research is to develop and test an objective technique to verify ensemble storm tracks with official storm tracks and objectively assign a quality metric to that match. Rather than focusing on any point along the tracks, the objective is to match overall tracks. In addition to permitting a better evaluation of the performance of the ECMWF ensemble in predicting actual storms, an objective assessment is obtained of missed JTWC storms, false alarms (FAs), and correct negatives (CNs; no ensemble storms predicted and no storms formed in the basin during the forecast interval).

* *Corresponding author address:* Dr. Hsiao-Chung Tsai, Department of Meteorology, Naval Postgraduate School, Monterey, CA 93943; e-mail: htsai@nps.edu

2. DATA AND METHODOLOGY

2.1 DATA

The 6-hourly JTWC best-tracks and ECMWF monthly ensemble forecasts during the 2009 and 2010 seasons are used in this study. The ECMWF monthly forecast model is a 32-day, 51-member ensemble forecast system. The horizontal resolution is T399 (~ 60 km) with 62 levels during the first 10 days. During days 10-32, the resolution decreases to T255 (~ 80 km). A tropical cyclone (TC) tracking routine was used by the ECMWF to extract the TC-like vortex track positions and intensities predicted by each of the ensemble members in the western North Pacific. Then the WMVM technique was applied to form the ensemble storm tracks for the forecast performance evaluations in this study.

2.2 OBJECTIVE TRACK MATCHING CRITERIA

The focus in this track matching procedure is to match large portion of the track. Given a JTWC storm, the data base of ensemble storms for the season are searched to find all ensemble storms within the allowable time difference of any time in the JTWC track: ± 3 days for Week 1, ± 4 days for Week 2, and ± 5 days for Weeks 3 and 4 forecasts. Both the shortest distance between any matched points and the average distance between all matched points are calculated. To avoid matching just the latter portion of the JTWC track, the time of the shortest distance match is checked to see if it is beyond the mid-time of the JTWC track. If true, then the number of hours from the beginning of the ensemble storm to the time of the shortest match must be greater than one third of the time interval from the beginning of the JTWC track to the shortest match time. For an ensemble storm to be considered as a match to the JTWC storm that formed in Week 1 of the forecast, the average distance (D_{avg}) must be less 10° and the shortest distance (D_{short}) must be less than 7°. In addition, the formation distance (D_{form}) and ending distance (D_{end}) must less than 7°. To allow for greater uncertainty in Weeks 2-4, these distance criteria were relaxed to 12° and 8°. These criteria ensure that all reasonably likely ensemble storms were considered as possible matches for the JTWC storm.

2.3 OBJECTIVELY DETERMINED QUALITY MEASURE

Elsberry et al. (2010, 2011) had subjectively assigned quality measures of Excellent, Above Average, Good, Below Average, and Poor to the ensemble storms that had been identified as matches for JTWC storms. To objectively determine the similarity between the ensemble storms matched by the typhoon analog approach in section 2.2, a likelihood value (LHV) was calculated:

$$LHV = 0.3 \times MF_{avg}(D_{avg}) + 0.25 \times MF_{short}(D_{short}) + 0.23 \times MF_{form}(D_{form}) + 0.22 \times MF_{end}(D_{end}) \qquad (1)$$

where the MFs are the membership functions (Fig. 1) for the D_{short}, D_{avg}, D_{form}, and D_{end} between the ensemble storm and the verifying JTWC storm. Similar applications utilizing membership functions and weights to combine selected information for meteorological forecasts can be found in the National Center for Atmospheric Research (NCAR) Auto-Nowcast System (Mueller et al. 2003) and Tsai et al. (2011). Notice that the larger weighting factors are assigned to the average distance and the shortest distance to emphasize the similarities with the overall JTWC track. In addition, a smaller weighting factor is given to the distance between the formation position of the ensemble storm versus that for the JTWC storm (i.e., max. intensity ≥ 25 kt). Finally, a weighting factor is assigned to the ending position difference to minimize matches of recurving and westward tracks between the ensemble storm and the verifying JTWC storm.

The LHVs obtained by eq. (1) are then used to assign a quality measure for each potential matching ensemble storm depending on its similarity to a particular JTWC storm. The five quality measures ranging from Excellent to Poor are assigned as a linear function of the LHV values from 1 with an interval of 0.2. A LHV < 0.2 (i.e., Poor) is considered to not be a real match of the ensemble storm with that JTWC storm.

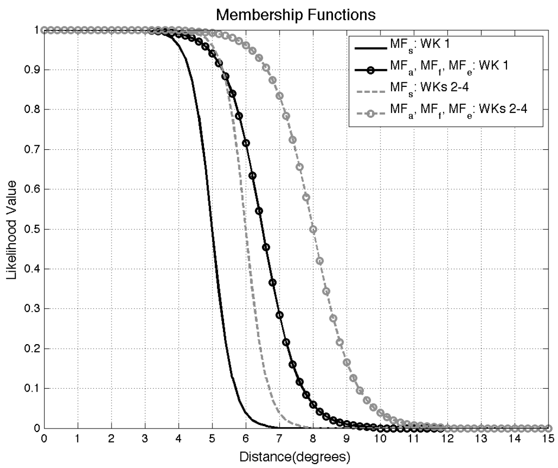

Fig. 1. The membership functions used in this study.

3. PRELIMINARY SUMMARY OF THE FORECAST PERFORMACE IN THE WESTERN NORTH PACIFIC

By using the LHV and the five quality measures defined in section 2, it is found that the proposed method shows a good consistency with the result in Elsberry et al. (2011). Table 1 is the summary of the ECMWF 32-day ensemble forecast performance in 2009 season (2 Jul to 31 Dec 2009). The evaluation result shows that the ECMWF 32-day ensemble forecasts can predict most of the JTWC storms in 2009. However, the false alarms are a major issue that needs to be addressed. As shown in Table 1, minimum FAs with no misses can be found in in Week 2 forecasts. Week 1 forecasts have more FAs than in Week 2. Similar results can be found in the 2010 FAs. It is also found that the formation lead times of the FAs during t=0-24 h are about 50% of the total number of the FAs in Week 1. By contrast, the frequencies of the FA formation lead times in Weeks 2 to 4 are more uniform. Elsberry and Chollet (2010) and Park et al. (2012) suggested that the ECMWF analyses have too-vertical convective towers rather than tilted updrafts. Therefore a strong tendency would exist to create FAs in Week 1 right from t= 0 h.

Given the objective definitions of false alarms, the characteristics of the FAs and comparisons of the Hits and FAs are investigated. Figure 2 shows the formation locations and the tracks of the FAs in 2010. The frequencies of the FA tracks are higher in the southern South China Sea than in the other regions. Compared to the FAs in 2009, which was an El Niño year, the mean formation locations of the FAs in 2010 are more westward. The average difference of the formation locations between the FAs in 2009 and 2010 is 13.16°.

The intensity (Vmax) and the maximum number of the ensemble member vortices within an ensemble storm (Nmax) for the Hits are compared with the Vmax and Nmax for the FAs. The Vmax of the Hits are larger than that of the FAs in Weeks 1-4 forecasts. Similar results can be found in the Nmax comparisons.

Table 1. The summary of the ECMWF 32-day ensemble forecasts in 2009 season (2 Jul to 31 Dec 2009). The definition of Hits: LHV≥ 0.2.

	Hits	FAs	Misses	CNs
Week 1	22	38	2	2
Week 2	24	20	0	8
Week 3	20	39	1	2
Week 4	20	72	1	2

4. SUMMARY

The proposed track analog verification method and the quality measure could provide an objective way to evaluate the track forecasts in the ensemble forecast model. The false alarms could be objectively identified. Since the proposed verification process is not person-dependent, the verification result could be more consistent, and could be easily modified and reproduced. The ECMWF 32-day ensemble forecast system could predict the formations and the tracks of tropical cyclones, even for the tropical depressions. However, the false alarms are a major issue to be addressed. Several approaches to reduce the number of false alarms are under evaluation.

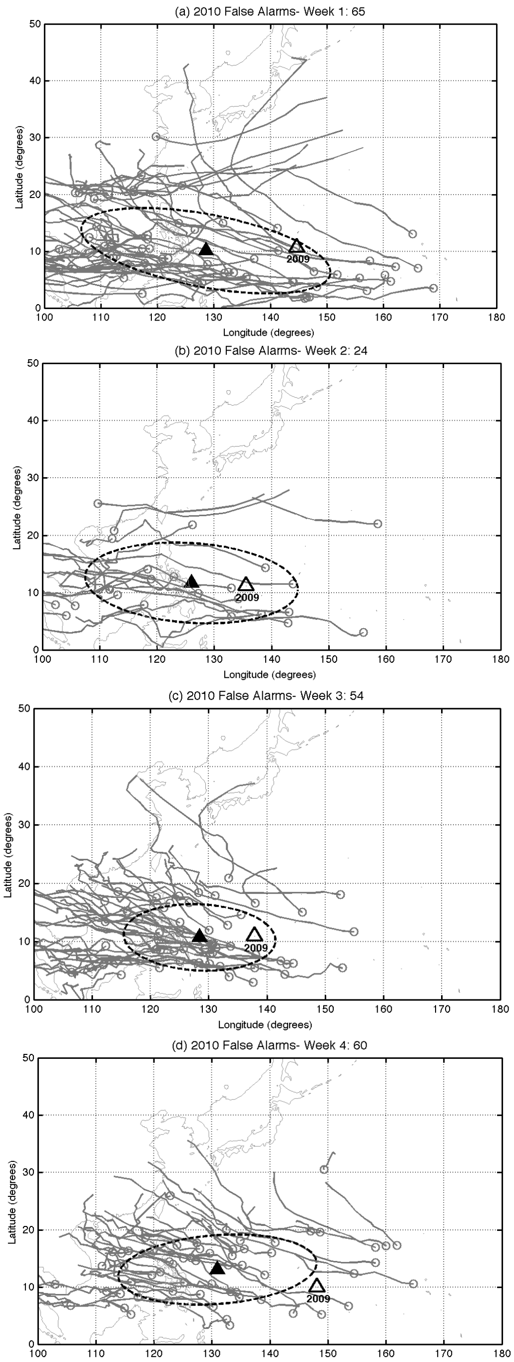

Fig. 2. The formation locations (open circles) and the tracks (lines) of the false alarms in 2010: (a) week 1, (b) week 2, (c) week 3, and (d) week 4 forecasts. The triangles are the mean formation locations, and the dashed ellipses are the 2-D Gaussian fitting of the formation locations outlined at one standard deviation (~68.26% probability). The mean formation locations of the false alarms in 2009 (open triangles) are also shown in the figures.

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