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NOTE

Critical Time Requirements for Operational Use of Deterministic and Ensemble Tropical Cyclone Track Forecasts

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Abstract: Tropical cyclone track forecasts have been improved, and forecast intervals have been extended to five days, owing to improved global and regional numerical model guidance. Critical time requirements that must be met for operational use of the deterministic model track forecasts are summarized for the U.S. and other selected non-U.S. tropical cyclone warning centers. One of the most accurate deterministic model forecasts from the European Center for Medium-range Weather Forecasts arrives too late to be used with other models at the + 6 h warning time, and thus is at least 12 h old before it can be operationally used. The time-critical nature of the tropical cyclone warning system is a major obstacle to operational use of single-model, or proposed multi-model, ensemble prediction system (EPS) mean and spread information, which is 12 h (or 18 h) delayed. This EPS mean and spread must also be superior to the mean and spread of the consensus of deterministic models that are available six hours earlier. These requirements must be met before the EPS tropical cyclone tracks will be operationally useful in specifying the uncertainty in the official track forecasts, which is the next challenge in tropical cyclone track warnings.

Key words: Tropical cyclone track prediction, deterministic numerical model track forecasts, ensemble and multi-model ensemble track forecasts

1. Introduction

The first purpose of this short note is to emphasize that a proper evaluation of the utility of model guidance for tropical cyclone track forecasts must consider the critical arrival-time of the numerical model guidance, and thus what information was actually available to the forecaster when the official track forecast was issued. This issue was first raised when tracks from early numerical models were being compared with statistically-based tracks. Since these numerical models could not be integrated until the synoptic observations were received and analyzed, the model forecast tracks did not arrive until more than 2.0 - 2.5 hours after synoptic time when the official forecast had to be issued. By contrast, the climatology and persistence and the statistically-based track guidance were calculated locally and therefore were available to the forecaster prior to official forecast release time. It was thus not proper to compare the numerical model track errors with the track forecast errors for the statistically-based techniques or the official track errors when that numerical model guidance was not available in time.

The second issue to be discussed here is that it is critical at what time the ensemble prediction system (EPS) tracks (e.g., from the THORPEX Interactive Grand Global Ensemble - TIGGE) become available at the warning center. In section 2, the procedures at the U. S. National Hurricane Center (NHC) for treating the late-arriving deterministic model track forecasts are first reviewed. Similar arrival-time requirements at other tropical cyclone warning centers are then summarized. Arrival-time considerations and the accuracy requirements for the single-model or multi-model EPS track forecasts are discussed in section 3.

2. Arrival-time considerations for deterministic model guidance

a. U. S. tropical cyclone warning centers

Consider the six-hour forecast cycle (Fig. 1) at the NHC beginning (t=00:00) at any of the four synoptic times (0000 UTC, 0600 UTC, 1200 UTC, 1800 UTC). By 00:45, the satellite-based fixes have been received, and the warning position at the synoptic time is then determined, which is used to provide the numerical models with a starting point for integration, which is referred to in Fig. 1 as "initialize the models." At 1:10 (Fig. 1), the track forecasts from the 'late-arriving" deterministic models are translated such that the 6-h forecast position coincides with the new warning position for those models that were integrated from initial conditions six hours ago. If the most recent forecast model integration was begun 12 h ago, the track forecast is translated such that the 12-h forecast position coincides with the new warning position. In the NHC terminology, this "late" model guidance is labeled as "interpolated," e.g., Geophysical Fluid Dynamics Laboratory (GFDI).

The translation of the track forecast to begin at the new

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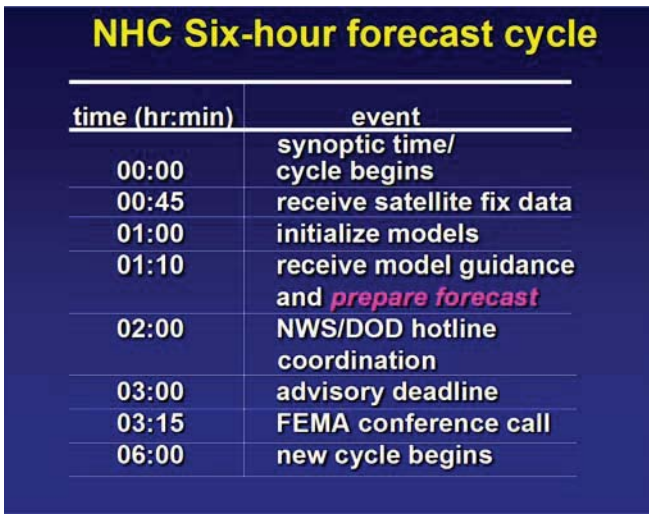

Fig. 1. Events in National Hurricane Center (NHC) six-hour tropical cyclone forecast cycle relative to the time = 00:00 of the synoptic observations (0000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC). Acronym definitions: NWS - National Weather Service; DOD - Department of Defense; FEMA - Federal Energy Management Administration. (provided by Dr. James Franklin, NHC)

warning position is particularly advantageous for the European Center for Medium-range Weather Forecast (ECMWF) tropical cyclone track forecasts. Since the ECMWF does not insert synthetic observations to improve the initial position and structure of the tropical cyclone, occasionally the forecast track begins from a somewhat anomalous position. The translation procedure that adjusts the entire forecast track to begin from the + 6 h (or + 12 h) warning position compensates for these tracks that are well offset from the actual position. Nevertheless, the ECMWF track forecasts are still one of the most accurate numerical models after 36-72 h.

The key point is that a proper comparison of track forecast errors relative to the verifying best-track positions is to only compare this interpolated numerical model guidance with the official track errors since this is the guidance that the forecaster had available at the warning time. As will be described in section 3, this point is also applicable for the ensemble prediction system (EPS) tropical cyclone tracks.

One of the primary model guidance products used at NHC (and other warning centers - Elsberry, 2007) is a consensus of selected deterministic numerical model tracks, which is simply an average of these model forecast positions each 6 h. Each of these model track forecasts has been translated to begin at the new warning position, so the consensus track also begins at the warning position and produces good guidance as to the future track. Goerss (2007) has also demonstrated that the spread (root-mean-square difference) of the model positions about the consensus track position, in combination with other predictors such as the latitude and longitude, is a useful indicator of the uncertainty of the consensus track forecast.

The ECMWF deterministic track forecast may not arrive by 01:00 for initialization with the other models (Fig. 1). However, James Franklin, Hurricane Specialist Unit Branch Chief at NHC, states that if the ECMWF initialized track forecast does arrive prior to 02:00, it will be considered because these forecasts typically have smaller errors at longer forecast intervals than the other model guidance. Notice that the Atlantic track forecast procedure is essentially complete prior to 02:00 when the coordination calls begin. Whereas some new observation (e.g., an aircraft fix) may prompt a change in the forecast, it is not late model guidance that would cause the NHC forecaster to make a change. In practice, the numerical guidance really needs to be available at the NHC by 01:00 to be most useful (Fig. 1). Consequently, the ECMWF track forecasts from 0000 UTC or 1200 UTC have very limited influence on the 0600 UTC or 1800 UTC warnings, respectively, and are primarily used for the subsequent 1200 UTC or 0000 UTC warnings, i.e., with a 12-h lag.

The NHC is also responsible for eastern North Pacific tropical cyclones east of 140°W, and the same timeline (Fig. 1) applies except there is no 02:00 coordination call (Fig. 1) so that some more time is available to receive the ECMWF track guidance and finalize the official forecast. The Central Pacific Hurricane Center is responsible for the 140°W-180°W region and operates on the same timeline. Finally, the U. S. Joint Typhoon Warning Center (JTWC) also operates in the same mode for the deterministic model tracks.

b. Other tropical cyclone warning centers

The Taiwan Central Weather Bureau has a more rigid time schedule than in Fig. 1 because the warning must be issued at synoptic time plus 00:30 (Table 1). To meet this schedule, the forecaster generates a preliminary guess of the warning position at 30 minutes prior to the synoptic time, which is then used to initialize the deterministic model tracks available by that time. That is, the model tracks are translated so that the + 6 h (or + 12 h) forecast positions begin at this initial guess warning position. This tight schedule does not allow inclusion of the synoptic time minus 6 h deterministic ECMWF track forecast that is not received until 2-3 hours after the 00:30 official forecast release time. The official forecast is then based on a consensus of the available deterministic model tracks that originates from an updated warning position based on the satellite imagery through 00:00.

The Regional Specialized Meteorological Center (RSMC) Tokyo Typhoon Center releases their 72-h forecast by 00:50 and their 120-h forecast by 01:30 (Table 1). Their warning position is established by 00:30. Their primary numerical model track guidance is the Japan Meteorological Agency (JMA) Global Spectral Model and Typhoon Ensemble Prediction System,

Table 1. Critical times relative to the synoptic time for positioning, initialization of the deterministic model guidance (from previous 6 h or 12 h synoptic time) with special consideration of the ECMWF receipt time, and the official forecast release time for selected tropical warning centers (Acronyms: NHC-National Hurricane Center; CPHC-Central Pacific Hurricane Center; JTWC-Joint Typhoon Warning Center; CWB-Central Weather Bureau; RSMC-Regional Specialized Meteorological Center; B Met-Bureau of Meteorology, which includes Darwin, Brisbane, and Perth offices).

	Warning Position Time	Deterministic Model Initialization Time	Deterministic Model Forecast Interpolation(s)	ECMWF Arrival Time	Official Forecast Release Time
NHC (CPHC) (JTWC)	00:45	01:00	+ 6 h + 12 h	≥ 01:00	03:00
Taiwan (CWB)	- 00:30 (prelim) 00:10	-00:20	+ 6 h + 12 h	≥ 02:30	00:30
RSMC-Tokyo	00:30	00:30	+ 6 h	02:00	00:50 (72 h) 01:00 (120 h)
B Met	00:00	-01:00	+ 6 h + 12 h	-01:00/ -02:00	-01:00

which are available each six hours at approximately four hours after synoptic time. By contrast, the ECMWF, UK Met, and NCEP model guidance is not available until eight hours after the t -6 h synoptic time, and thus arrive after the official forecast release times (00:50, 01:30; Table 1).

The Australia Bureau of Meteorology has Tropical Cyclone Warning Centers (TCWCs) in Darwin (Northern Territories), Brisbane (Queensland), and Perth (Western Australia). These three centers have a common warning position determination time of 00:20 and official forecast release time of 01:00 (Table 1). Each of the TCWCs initializes the dynamic models at the same time -01:00 as all of the TCWCs have most of the global deterministic models an hour before the official forecast release time. However, the ECMWF deterministic model track forecast arrives between 01:00 and 02:00, and this is too late to contribute to the official forecast (Table 1). Although the ECMWF model output is available in graphical form prior to this time, this is not suitable for electronic ingestion into the TCWC operational warning platform called TCModule.

In summary, all of the non-U.S. centers surveyed have a more restrictive official forecast release time that determines what deterministic numerical model guidance can be utilized in generating the official forecast. Except for the RSMC-Tokyo that relies on internal JMA model guidance, the other warning centers rely on a consensus of deterministic models initiated from observations six (or 12) hours earlier. The delayed ability of the ECMWF deterministic model track forecast means it will not be used until 12 h, if at all, at these non-U.S. centers. This fact illustrates the critical time requirement for operational use of deterministic model tropical cyclone track forecasts.

3. Arrival time considerations for EPS track guidance

The NHC routinely receives the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) EPS in time for the synoptic time plus 6 h forecast cycle. Since the GFS EPS is integrated each 6 h, this ensemble track guidance is available for every forecast cycle in Fig. 1. According to James Franklin, the NHC forecasters focus on the GFS ensemble mean track, but preference is given to the consensus of multiple deterministic models that has smaller errors than the single-model ensemble such as the GFS EPS. The rationale is that the consensus of multiple skillful models tends to average out random errors. It is also generally true that the ensemble mean track tends to follow the higher-resolution "mother" deterministic model track. Furthermore, the spread of the consensus model tracks is found to be a better indicator of forecast uncertainty than is provided by the single-model EPS (Goerss, 2007).

As indicated in section 2b, the RSMC-Tokyo has the JMA TEPS, which is an 11-member regional EPS, in time for use in preparing the official forecasts that are issued at 00:50 (72 h) and 01:30 (120 h). Indeed, the TEPS is one of the primary sources of guidance each 6 h, which is only possible due to its availability in relation to the RSMC-Tokyo time schedule (Table 1).

Since even the ECMWF deterministic model track may not arrive at NHC by the 01:00 model initialization time (Fig. 1), the ECMWF ensemble, which is an integration of 51 members on a more coarse horizontal resolution, does not arrive until well after the official forecast has been prepared and released by 03:00. At NHC, only the ECMWF ensemble mean track is displayed on their Automated Tropical Cyclone Forecast (ATCF) display - not the 51-member ensemble tracks. Because of its late arrival,

this ensemble mean track is not interpolated to the +12 h warning position. One reason is that the ECMWF deterministic track has been found to be more accurate than the ensemble mean track. However, the delayed receipt of the ensemble mean track forecast is the primary reason little use is made of the ECMWF ensemble at the NHC.

One expected benefit from an EPS is a measure of the uncertainty in the forecast. In the case of track forecasts, the key question is whether the spread of the ensemble member tracks about the ensemble mean indicates the accuracy of the track forecasts. The Perth office of the Australia Bureau of Meteorology compared the ECMWF ensemble track spread and the track forecast errors in their region and the spread did not provide a better measure of the track uncertainty than simply using the long-term average forecast error (personal communication, Mike Bergin, Director, October 2009). As indicated above, the NHC forecasters prefer to use the spread about the consensus mean of the higher resolution mother deterministic models than the single-model ensemble. At the Taiwan Central Weather Bureau (CWB) where the ECMWF track spread display is available with a 10-11 h delay, the Chief of the Forecast Division Daniel Wu qualitatively considers the track "outliers" that may indicate a change in direction. As subsequent ensemble forecast track spreads have increased numbers of members that indicate a turn toward Taiwan, then this track scenario is increasingly considered as a possibility when examining the deterministic model track guidance.

Even if the ECMWF EPS spread does provide an accurate indication of track forecast error, it is proposed that a major obstacle to its use is the lack of timeliness in the receipt of the ensemble track spread, which is not useable to the forecaster until at least 12 h after the synoptic time on which it is based. Furthermore, the ECMWF EPS is only integrated from 0000 UTC and 1200 UTC initial conditions. If this track spread guidance is to be used for the 0600 UTC and 1800 UTC forecasts at NHC, it would be based on synoptic conditions that existed 18 h ago. By 12 h (or certainly 18 h) after synoptic time, new guidance from multiple skillful deterministic models with higher resolution is available.

Thus, the time-critical nature of the NHC forecast cycle (Fig. 1) is a major obstacle for EPS systems to provide useful guidance to the NHC forecaster. A proper evaluation of the EPS mean and spread for tropical cyclone prediction must account for this critical available-time factor and also be compared with the mean and spread of the consensus of skillful deterministic model guidance that is available in a more timely manner. The requirement is to demonstrate that the 12h (or 18 h) delayed EPS spread provides additional guidance as to the uncertainty in the track forecast beyond that provided by the deterministic model consensus guidance. It is emphasized that it is the uncertainty about the official forecast track that is required - not that about the ensemble mean track, which may be quite different.

Another proposed use of the ensemble tropical cyclone track predictions is a Global Interactive Forecast System (GIFS)/ TIGGE multi-model ensemble. The first rationale for this GIFS/ TIGGE approach is that a mean of the multiple EPS tracks may achieve a cancellation of systematic errors as for the consensus of deterministic models. The second rationale is that the combination of track spreads will provide a more complete probability distribution function of the possible tracks, and thus a better measure of the track forecast uncertainty. Although each of these rationales remains to be demonstrated, the large number of tropical cycle track forecasts from a combination of the TIGGE data sets may well have a potential contribution to specification of track forecast uncertainty.

The demonstration of the GIFS/TIGGE multi-model ensemble usefulness for tropical cyclone track forecasting must consider the two factors described above for single-model ensembles. First, the critical available-time factor for usefulness to an official track forecast must be considered, and specifically the 12 h (or 18 h) time delay must be accounted for in the validation. Second, the mean and spread of the multi-model ensemble must provide additional information beyond the mean and spread of the consensus of deterministic models from the 6-h prior integration that have been interpolated to begin at the new warning position (Fig. 1). Given the time delay in availability of the multi-model ensemble, the requirement is to demonstrate that the combined track spread information will provide a useful representation of the uncertainty in the official forecast track that is primarily based on a consensus of deterministic models integrated from more recent observations.

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